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**Preliminary Draft
Environmental Impact Statement for
Hot Fuels Engineering Laboratory**

J. W. Boyle
J. A. Carpenter
S. J. Cotter
F. E. Harrington

N. E. Hinkle
D. R. Johnson
R. L. Kroodsma
K. H. Lin

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PRELIMINARY DRAFT
ENVIRONMENTAL IMPACT STATEMENT FOR HOT FUELS ENGINEERING LABORATORY

J. W. Boyle^a, Task Group Leader

J. A. Carpenter^b, Jr.

S. J. Cotter^c

F. E. Harrington^d

N. E. Hinkle^a

D. R. Johnson^b

R. L. Kroodsma^e

K. H. Lin^d

Date Published: March 1980

^aEnergy Division

^bMetals and Ceramics Division

^cHealth and Safety Research Division

^dChemical Technology Division

^eEnvironmental Sciences Division

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It is subject to revision or correction and therefore does not represent a
final report.

OAK RIDGE NATIONAL LABORATORY

Oak Ridge, Tennessee 37830

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FORWARD

The "Preliminary Draft Environmental Impact Statement for the Hot Fuels Engineering Laboratory" set forth in this document was prepared in fiscal year 1979 under the auspices of the Consolidated Fuel Refabrication Program which was supported by the Nuclear Power Development Division of DOE. The Hot Fuels Engineering Laboratory had been proposed for two major reasons. It was seen as a timely means of meeting a perceived national need for a small scale developmental facility in which highly gamma-active, diversion-resistant fuels could be safely handled through limited engineering process development and early preparation of irradiation test specimens, and by utilizing an existing hot cell facility, the HFEL could meet the above need in a cost effective manner.

However, due to changes in emphasis of fuel development programs and a necessity to consolidate development activities, the proposal to complete the HFEL has been deferred indefinitely. The following document is published at this time to be available as a reference for those engaged in assessing other fuel facilities or other applications of the referenced facility.

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The International System of Units (SI) has been used throughout this report. The following table is provided to assist the reader in converting from the units used in this report to English units, if desired.

Conversion Table		
to convert from —	to —	multiply by —
<u>mass</u>		
gram (g)	ounce (avoirdupois)	0.03527
kilogram (kg)	pound (avoirdupois)	2.205
metric ton (1000 kg)	ton (2000 lb)	0.9072
<u>length</u>		
micrometer (μm)	micron (μ)	1.000
millimeter (mm)	inch	0.03937
centimeter (cm)	inch	0.3937
cm/sec	ft/sec (fps)	0.03281
meter (m)	foot	3.281
m/sec	ft/sec (fps)	3.281
kilometer (km)	mile	0.6215
km/hr	mile/hour (mph)	0.6215
<u>area</u>		
square meter (m^2)	square foot (ft^2)	10.76
hectare (ha)	acre	2.471
square kilometer (km^2)	square miles	0.3861
<u>volume</u>		
liter (l)	gallon	0.2642
liter per second	cubic foot per second (cfs)	0.03531
liter per minute	cubic foot per minute (cfm)	0.03531
cubic meter (m^3)	cubic foot (ft^3)	35.31
cubic meter (m^3)	acre-foot	0.8107×10^{-3}
cubic meter per second	cubic foot per second (cfs)	35.31
cubic meter per day	million gallon per day (Mgd)	0.2642×10^{-3}
<u>temperature</u>		
$^{\circ}\text{C}$ (Celsius)	$^{\circ}\text{F}$ (Fahrenheit)	1.8 and add 32

1. SUMMARY

The proposed action considered in this report is the construction and operation of the Hot Fuels Engineering Laboratory (HFEL) to be located in Building 7930, the Thorium-Uranium Recycle Facility (TURF), at Oak Ridge National Laboratory. The successful operation of the HFEL, as described in this report, will provide generic demonstrations of safe, economical fuel fabrication processes for fuels which are inherently highly radioactive or fuels to which a high level of radioactivity has been added to reduce the probability of illicit diversion.

The proposed action will demonstrate the process and equipment remote operability with high levels of radioactivity present (up to 10,000 R/h). Three fuel fabrication processes will be tested: the gel-sphere-pac and sphere-cal processes for metal clad fuel pins and the production of HTGR-green-fuel-rods for insertion into graphite elements. Each process will be tested for two types of fuel: uranium-plutonium and ^{233}U -thorium. In each case, the product will be a small number of fuel pins or rods, which will be suitable for testing in other phases of the National Program Plan of the Department of Energy. The facility will accommodate other types of fuels and processes if so desired.

The impacts resulting from operational releases to the environment have been assessed. The assessment of accidental releases is covered in two documents, "Hot Fuels Engineering Laboratory Preliminary Hazards Analysis," Document X-OE-80, ORNL, September 1978, and "Hot Fuels Engineering Laboratory Hazard Assessment and Action Plan," X-OE-81, ORNL, September 1978. The major conclusions of the operational assessment are as follows:

1. No significant radiological impacts are expected from routine operation of the facility to any biota or ecosystem. The maximum individual dose commitments are well below the present NRC regulations of 500 millirems to the total body, 3000 millirems to the bone, and 1500 millirems to the lungs. Also, all annual doses are below future EPA standards for annual doses of 25 millirems to the total body, 75 millirems to the thyroid, and 25 millirems to all other organs. The estimated population dose commitment for total-body doses for the population living within 80 km of the site are lower (by a factor of over 10^6) than the corresponding population dose resulting from the natural background of the State of Tennessee (approximately 70,000 man-rems).
2. Nonradiological effects from construction activities and routine operation should be insignificant on land and water use and on terrestrial and aquatic ecosystems.
3. No significant socioeconomic impacts should occur from either construction or operation of the facility.
4. No large quantities of strategic or rare resources will be consumed or rendered useless by the project, and no significant long-term commitment of resources is expected to be required.

5. The principal alternatives considered were relocation of the project site, postponement of the project schedule, and project cancellation. Considering the objectives of the National Program Plan, none were judged to be as feasible as the proposed project.

2. DESCRIPTION OF PROPOSED ACTION

2.1 PURPOSE AND NEED

An objective of the National Program Plan of the Department of Energy is to develop the technology for safe and economic fuel cycles that offer less risk of illicit diversion of nuclear material. The successful operation of the Hot Fuels Engineering Laboratory (HFEL) will provide a demonstrated fuel fabrication technology, including facility requirements, interfaces, and support technology, and will provide the data base for construction of a lead high-gamma-fuel fabrication plant by 1995.

The HFEL is an essential step in the development program. This engineering test provides for (1) testing of equipment in an actual remote operating environment (presence of considerable radioactivity) and (2) an early fabrication of gel-sphere-pac fuel pins with the option for these pins to contain high-gamma fuel. The remote operating (and maintenance) experience will provide invaluable guidance in the design of the remote pilot plant. Testing of the engineering-scale equipment will produce spheres for various development activities (gel-sphere-pac, sphere-cal, and HTGR-green-fuel-rod), including the preparation of test pins for an irradiation test qualification program.

The Hanford Engineering Development Laboratory has been selected by the Department of Energy as the Reactor Fuels and Materials Technology Management Center (TMC). The TMC will direct the development program as it proceeds from lab-scale process development and remote engineering test to remote pilot-plant demonstration.

Under the overall Reactor Fuels and Materials Development Program, the Oak Ridge National Laboratory will have a major role in development work for particulate fuel. This development is at an early stage relative to fabrication of conventional pellet fuel. Considerable process development has been done, but engineering equipment development is only beginning. Three sizes (about 1200, about 300, and about 30 μm) of dense (over 99% of theoretical density) spheres have been produced and fabricated into fuel rods.

All fuel systems will be fabricated as pellets or as packed particles (sphere-pac). Pellets are the current preferred route because of the large amount of commercial experience. Particles (microspheres) have the backup assignment. Microspheres are recognized as attractive for remote operations and essentially dust-free material handling. Microspheres are used in the preparation of HTGR fuel and are being considered as feed for pellet making.

The conceptual design¹ of facility modifications required by the HFEL has been completed. The modifications and additions to the existing Thorium-Uranium Recycle Facility (TURF) will provide a generic remote fabrication development facility that meets current safety, natural phenomena, and safeguards requirements.

The Conceptual Design Report¹ presents costs for starting design early in FY 1981. A probable one-year deferral due to program priorities is being evaluated in terms of program impact and cost escalation.

2.2 DESCRIPTION OF HOT FUELS ENGINEERING LABORATORY

The HFEL facility will provide a generic process equipment line suitable for demonstrating the remote refabrication of fuel pins and rods for various reactors — light-water, fast breeder, gas-cooled, heavy-water, etc. Both uranium-plutonium and ²³³U-thorium fuels will be accommodated. The process equipment will be chosen so that the above fuel types can be refabricated into pins or rods in campaigns in a single line of process equipment. Process and equipment tests will be performed on a unit-process basis. Simultaneous integrated tests of all unit processes are not planned. Current operational plans utilize a two-shift-per-day, five-day-per-week basis, with most work done on the day shift. About 10 to 15 fuel rods meeting Fast Flux Test Facility specifications and a lesser number of light-water reactor fuel rods could be prepared in a week. The material balance calculations and source terms have been calculated for the most conservative case — continuous production at the maximum rate with the maximum radioactive content.

The radiation shielding, personnel protection, remote handling and maintenance capabilities, and other features of the HFEL will permit the fabrication of reactor pins and/or rods of extremely gamma-active (low decontamination factor or spiked) diversion-resistant fuel. Radiation environments of 10,000 R/h from ⁶⁰Co or other spikants may be accommodated by the facility and process equipment.

2.2.1 Site

The HFEL will be located in Building 7930 in Melton Valley at ORNL (Fig. 2.1). The location of ORNL with respect to the surrounding area and the State of Tennessee is shown in Fig. 3.1. Building 7930, known as the Thorium-Uranium Recycle Facility (TURF), is a three-floor building with a gross floor area of 3300 m². The facility is divided into five major areas as shown in Fig. 2.2: (1) a cell complex containing seven hot cells (six shielded and one unshielded), (2) a receiving area for radioactive materials, (3) an operating area with a development laboratory, chemical makeup area, and equipment rooms for facility service equipment, (4) an office and conference area adjacent to but isolated from areas that contain radioactivity, and (5) a maintenance operating area with service areas for radioactive materials. The building is provided with a fire-sprinkler system; the cells, with an automatic Halon fire-deterrent system.¹ The HFEL process equipment will be located within the shielded cells (Fig. 2.3).

2.2.2 Fuels

Use of two types of fuel has been considered in this report to demonstrate the versatility of the facility. Ten kg of heavy metal will be processed each week. Mass flows and the composition of chemical streams and environmental discharges are based on this rate. A brief description of each type of fuel follows.

2.2.2.1 Uranium-plutonium fuel

The composition of the uranium-plutonium fuel is shown in Table 2.1. Both the mass of each element and the curies of each nuclide are given for a single campaign (10 kg of heavy metal, initial charge). In the base case (gel-sphere-pac) it is assumed that all the uranium is

Fig. 2.1. Aerial photograph showing positional relationship of TURF to other ORNL facilities.

ORNL-DWG 78-3524CO

Fig. 2.2. Cutaway drawing of TURF showing major functional areas of building.

Fig. 2.3. First-floor plan of Building 7930 (TURF). To convert dimensions to meters, multiply by 0.305.

initially present as ammonium diuranate, $(\text{NH}_4)_2\text{U}_2\text{O}_7$, and the plutonium as plutonium dioxide, PuO_2 . The uranium consists of four isotopes whose abundance, presented as curie-percent, consists of ^{234}U , 59.8; ^{235}U , 1.2; ^{236}U , 17.5; and ^{238}U , 21.5. The plutonium has the following curie-percent composition: ^{238}Pu , 1.8; ^{239}Pu , 0.3; ^{240}Pu , 0.4; ^{241}Pu , 97.5; and ^{242}Pu , 0.1. The spikant consists of over 1000 Ci of ^{60}Co per campaign. The curium is over 99% ^{244}Cm .

2.2.2.2 ^{233}U -Thorium fuel

The composition of the ^{233}U -uranium-thorium fuel is shown in Table 2.2. It is assumed that initially all of the uranium is present as ammonium diuranate and the thorium as thorium dioxide (ThO_2). The spikant is about 1200 Ci of ^{60}Co .

2.2.3 Processes

A functional flowsheet for the HFEL is shown in Fig. 2.4. Figure 2.4 indicates the three processes planned for the HFEL — the basic process referred to as gel-sphere-pac, option 1 referred to as sphere-cal, and option 2, a process that produces HTGR green fuel rods. Both uranium-plutonium and ^{233}U -thorium reactor fuels are considered for each of the three processes, resulting in the environmental analysis of six cases.

Figure 2.5 shows a schematic waste-stream flow sheet. Gaseous waste products, both radioactive and nonradioactive from all three processes, are discharged to the atmosphere from two points, the 7911 stack and a standpipe on the roof of Building 7930. All liquid wastes, containing both radioactive and nonradioactive chemicals, are routed to the ORNL ILW (intermediate-level waste) facility. A decontamination factor (DF) of 10^7 is provided for all aqueous discharges from this facility that are released to White Oak Creek. Concentrated wastes from the ILW are disposed of by hydrofracture.

Table 2.1. Composition of single campaign
of uranium-plutonium fuel
Major radionuclides

Constituent	Amount
Heavy metals	
U (g/week)	6520
(Ci/week)	0.03
Pu (g/week)	3478
(Ci/week)	4.703(4) ^a
^{242,244} Cm (g/week)	2(-6)
(Ci/week)	1.1
Fission products and other	
⁹⁵ Zr (g/week)	0.027
(Ci/week)	570
⁹⁵ Nb (g/week)	0.01
(Ci/week)	392
^{103,106} Ru (g/week)	0.272
(Ci/week)	996
¹³⁴ Cs (g/week)	5(-4)
(Ci/week)	0.6
¹³⁷ Cs (g/week)	0.003
(Ci/week)	0.3
¹⁴⁴ Ce (g/week)	0.016
(Ci/week)	50
¹⁵⁴ Eu (g/week)	3.1(-3)
(Ci/week)	0.8
⁶⁰ Co (g/week)	1
(Ci/week)	1141
Total Co (g/week)	23

^a4.703(4) means 4.703×10^4 , etc.

2.2.3.1 Gel-sphere-pac fuel pin fabrication

This report is concerned with the releases to the environment (primarily to the atmosphere and White Oak Creek) as illustrated in Fig. 2.5. For a detailed description of the gel-sphere-pac fuel pin fabrication process itself, the reader is referred to Appendix A.

Gaseous wastes

Gaseous discharges to the atmosphere are treated before release to reduce the radioactivity to acceptable levels. Three off-gas systems will be provided in TURF to handle gaseous waste streams. Each is discussed below.

Hot off-gas. The off-gas from process vessels other than those producing combustible off-gases flow to the hot-off-gas (HOG) system, described in detail in the TURF Safety Analysis Report.² From the process vessels the off-gas flows to and ventilates the liquid-waste holding tank. A charcoal adsorption bed will be provided between the liquid-waste holding tank and the present bank of HEPA filters to provide a 15-min holdup of radon. From the adsorption bed, the off-gas stream flows through one of two parallel banks of filters consisting of two roughing filters and four HEPA filters in series. For particulates, semivolatiles, and condensable vapors, a DF of 10 is assumed for each roughing filter, 2×10^3 for the first of the four HEPA filters, and 2×10^2 for each of the three succeeding HEPA filters (total DF, 1.6×10^{12}).

Table 2.2. Composition of single campaign
of ^{233}U -thorium fuel

Major radionuclides	
Constituent	Amount
Heavy metals	
U (g/week)	2730
(Ci/week)	35.7
^{232}U (g/week)	0.568
(Ci/week)	12.2
^{233}U (g/week)	2483
(Ci/week)	23.5
^{235}U (g/week)	1.6
(Ci/week)	3(-6)
^{238}U (g/week)	244.8
(Ci/week)	8(-5)
^{239}Pu (g/week)	0.049
(Ci/week)	3(-3)*
Th (g/week)	7290
(Ci/week)	2.4(-3)
^{228}Th (g/week)	5(-7)
(Ci/week)	4(-4)
^{232}Th (g/week)	7290
(Ci/week)	2(-3)
Other	
^{60}Co (g/week)	1.1
(Ci/week)	1211
Co (g/week)	24
^{219}Rn (g/week)	9.57(-19)
(Ci/week)	1.23(-8)
^{220}Rn (g/week)	1.87(-8)
(Ci/week)	17.07
^{222}Rn (g/week)	9.5(-14)
(Ci/week)	1.47(-8)

*3(-3) means 3×10^{-3} , etc.

From the bank of HEPA filters, the off-gas flows to and connects with the cell ventilation system described below.

Cell ventilating system. The exhaust system of each cell is equipped with a roughing filter. The cell off-gases flow to the cell exhaust filter pit, where they join the effluents from the HOG system described above. In the cell exhaust filter pit, the gases flow through one of five parallel banks of filters, each consisting of two HEPA filters in series. The exhaust system roughing filter of any cell is assumed to provide a DF of 10 for particulates, semi-volatiles, and condensable vapors. A DF of 2×10^3 is assumed for the first HEPA filter and 2×10^2 for the second. From here the off-gases flow to the 7911 stack and are vented to the atmosphere.

Combustible off-gas system. A special combustible off-gas system, to handle the off-gases from the debonding, sintering, and HTGR particle coating furnaces, will be provided. The system is assumed to be essentially like that envisioned in the conceptual design study for the HTGR Hot Engineering Test Facility.³

Fig. 2.4. Functional diagram for the Hot Fuels Engineering Laboratory.

The off-gases from the furnaces first pass through one of two parallel HEPA filters, a charcoal adsorption bed, one of two other parallel HEPA filters, and then through a flame arrester to a standpipe on the building roof, where it is vented to the atmosphere. Each HEPA filter is assumed to provide a DF of 2×10^3 for particulates, semivolatiles, and condensable vapors. The charcoal adsorption bed is assumed to provide a 15-min delay for all the radon emitted.

Gaseous source terms. The maximum weekly operational releases from the HOG and cell ventilation systems through the 7911 stack and the combustible off-gas through the 7930 roof standpipe for uranium-plutonium and ^{233}U -thorium fuels are presented in Tables 2.3 and 2.4. These source terms were determined by summation of the activities in the gaseous effluent streams of the gel-sphere-pac process, given in Appendix A (Tables A-3 and A-6), incorporating the appropriate decontamination factors given above.

Liquid wastes

There will be liquid organic wastes and two types of aqueous liquid wastes, namely, intermediate-level wastes (ILW) and process wastes, generated by HFEL operations in TURF. Nonradioactive chemical waste streams are sent to the ILW system.

ILW waste system. Waste streams that make up the ILW wastes are (1) the evaporator condensate, (2) the gel-sphere wash solution, (3) the sphere-drying condensate from dry microsphere prepara-

Fig. 2.5. Schematic diagram showing HFEL waste streams.

tion, the condensates from the off-gas streams of the (4) debonding and (5) sintering furnaces, and (6) the caustic scrubber solution from HTGR particle coating. These ILW liquids are collected in special tanks in TURF and are eventually pumped via stainless steel lines to the ORNL ILW system in Bethel Valley.

In the ORNL ILW system, the ILW liquids are concentrated by a factor of 20 to 30. A DF of 10^5 for all constituents (radionuclides and chemicals) is assumed for the ORNL ILW evaporator overhead condensate. The overhead is condensed and fed to the ORNL Process Waste System, where further processing provides an additional DF of 10^2 . The bottoms are stored prior to geologic disposal by the shale-fracturing process.

The shale-fracturing process is a waste disposal method currently in use at ORNL for the permanent disposal of locally generated ILW solutions.^{4,5} In this process the waste solution is mixed with a solids blend of cement and other additives; the resulting grout is injected into an impermeable shale formation at a depth of 200 to 300 m, well below the level of groundwater. The initial fracture in the shale is generated by the hydraulic pressure of a small volume of water. Grout containing waste is then injected into this initial fracture. The injection pressure is sufficiently high to propagate a thin horizontal crack in the shale. As the injection of the grout continues, this crack is filled by the grout and is further extended so that a thin, approximately horizontal, grout sheet several hundred feet across is formed during the course of the injection. The grout sets a few hours after completion of the injection, thereby permanently fixing the radioactive wastes in the shale formation. Subsequent injections form sheets parallel to the first injection and a few feet above it.

Table 2.3. Weekly operational discharges^a to the atmosphere from uranium-plutonium gel-sphere-pac fuel pin preparation process

Constituent	7911 stack ^b	7930 standpipe ^c
Major radionuclides, ^d Ci		
Alpha emitters		
U ^e	3.0(-13) ^f	7.9(-12)
Pu ^g	4.7(-7)	1.2(-5)
Cm ^h	1.1(-11)	2.9(-10)
Gross alpha	4.7(-7)	1.2(-5)
Beta and gamma emitters		
⁶⁰ Co	1.2(-8)	3.0(-7)
⁹⁵ Zr	5.7(-9)	1.5(-7)
⁹⁵ Nb	3.9(-9)	1.0(-7)
¹⁰³ Ru	1.8(-9)	9.0(-8)
¹⁰⁶ Ru	8.2(-9)	4.1(-7)
¹³⁴ Cs	6.0(-12)	3.0(-10)
¹³⁷ Cs	3.0(-12)	1.5(-10)
¹⁴⁴ Ce	5.0(-10)	2.5(-8)
¹⁵⁴ Eu	8.0(-12)	4.0(-10)
Gross beta-gamma	3.2(-8)	1.1(-6)
Nonradioactive chemicals, ⁱ liters		
Water		8.7
Ammonia		5.8
Hydrogen		3,290
Argon		80,200

^a Assume uniform release rate during 40-h work week.

^b 7911 stack: height, 76.2 m; diameter, 152 m; normal air flow, 1020 m³/min; exhaust velocity, 2340 cm/s.

^c 7930 roof standpipe: height, 19.8 m; diameter, 5.2 cm; normal gaseous flow, 35 liters/min; exhaust velocity, 6.85 cm/s.

^d Released as particulates.

^e Uranium has a curie-percent of ²³⁴U, 59.8; ²³⁵U, 1.2; ²³⁶U, 17.5; ²³⁸U, 21.5.

^f 3.0(-13) means 3.0 X 10⁻¹³, etc.

^g Plutonium has a curie-percent composition of ²³⁸Pu, 1.8; ²³⁹Pu, 0.3; ²⁴⁰Pu, 0.4; ²⁴¹Pu, 97.5; ²⁴²Pu, 0.1.

^h Curie has a curie-percent composition of ²⁴²Cm, 1; ²⁴⁴Cm, 99.

ⁱ Released as gases (STP).

Process waste system. Process wastes include a myriad of streams, such as cooling water, that do not intentionally come in contact with radioactive material. These are collected in a retention pond near TURF and are tested for radionuclide contamination. If noncontaminated, they are released directly to Melton Branch. If contaminated, they are pumped to the ORNL Process Waste System.

Wastes received by the ORNL Process Waste System undergo a treatment consisting of scavenging, precipitation, and ion exchange. A DF of 10² for all constituents (radionuclides and chemicals) is assumed for the ORNL Process Waste System. The product liquid is monitored and discharged to White Oak Creek. The contaminants removed by the Process Waste System are sent to the ILW system for disposal.

Aqueous source terms. The maximum weekly operational release to White Oak Creek from the gel-sphere-pac fuel pin preparation process is given in Tables 2.5 and 2.6 for uranium-plutonium

Table 2.4. Weekly operational discharges^a to the atmosphere from
²³³U-thorium gel-sphere-pac fuel pin preparation process

Constituent	7911 stack ^b	7930 standpipe ^c
Major radionuclides, ^d Ci		
Alpha emitters		
²²⁰ Rn	6.8(-5) ^e	2.5(-4)
²²² Rn	8.1(-10)	1.5(-8)
²²⁸ Th	4.0(-15)	1.1(-13)
²³² Th	2.0(-14)	5.2(-13)
²³² U	1.2(-10)	3.2(-9)
²³³ U	2.4(-10)	6.1(-9)
²³⁹ Pu	3.0(-14)	7.8(-13)
Gross alpha	6.8(-5)	2.5(-4)
Beta and gamma emitters		
⁶⁰ Co	1.2(-8)	3.2(-7)
Nonradioactive chemicals, ^f liters		
Water		3.6
Ammonia		2.4
Hydrogen		1,150
Argon		33,300

^a Assume uniform release rate during 40-h work week.

^b 7911 stack: height, 76.2 m; diameter, 1.52 m; normal air flow, 1020 m³/min; exhaust velocity, 2340 cm/s.

^c 7930 roof standpipe: height, 19.8 m; diameter, 5.2 cm; normal gaseous flow, 14 liters/min; exhaust velocity, 2.82 cm/s.

^d Radon isotopes are released as gases; other radionuclides are released as particulates.

^e 6.8(-5) means 6.8×10^{-5} , etc.

^f Released as gases (STP).

and ²³³U-thorium fuels. The releases are via the ORNL ILW and Process Waste Systems and result in a net decontamination factor of 10⁷. The development of these source terms is given in greater detail in Appendix A.

Liquid organic wastes. Organic liquid waste will be generated in the microsphere preparation process. The waste consists primarily of trichloroethylene and its degraded products, which will be absorbed on vermiculite, encased in plastic, and disposed of by land burial (Tables 2.7 and 2.8).

Solid wastes

Solid waste from the gel-sphere-pac process will be disposed of by shallow land burial. The burial site currently in use at ORNL is solid-waste-storage-area 6. This 27.5-ha site, opened in 1969, was chosen because it had suitable hydrologic and geologic characteristics. The area has gentle relief for ease of operation and yet not subject to flooding, a soil easily excavated by earth-moving equipment and yet firm enough to withstand deep cuts, easily accessible within the restricted area of ORNL, sufficient depth to groundwater to permit depositing contaminated material above the water table (min 0.6 m), and, very important, underlain with Conasauga shale. Conasauga shale has ion exchange properties, which retards the migration of water-soluble nuclides. Wastes are normally placed in trenches (or auger holes) and covered with dirt. Trenches are nominally 3 m wide and 3 to 4.5 m deep and finally are covered with about 1 m of dirt. The auger holes may vary in diameter from 20 to 76 cm.

Table 2.5. Weekly operational releases^a to White Oak Creek from uranium-plutonium gel-sphere-pac fuel pin preparation process

Major radionuclides	Discharge to ILW system (Ci)	Release to White Oak Creek (Ci)	Concentration ^b in White Oak Creek (pCi/liter)
Alpha emitters			
U ^c	2.6(-5) ^d	2.6(-12)	5.7(-8)
Pu ^e	4.1(1)	4.1(-6)	9.0(-2)
Cm ^f	9.5(-4)	9.5(-11)	2.1(-6)
Beta and gamma emitters			
⁶⁰ Co	9.9(-1)	9.9(-8)	2.2(-3)
⁹⁵ Zr	4.9(-1)	4.9(-8)	1.1(-3)
⁹⁵ Nb	3.4(-1)	3.4(-8)	7.5(-4)
¹⁰³ Ru	1.7	1.7(-7)	3.7(-3)
¹⁰⁶ Ru	7.9	7.9(-7)	1.7(-2)
¹³⁴ Cs	3.0(1)	3.0(-6)	6.6(-2)
¹³⁷ Cs	1.5(1)	1.5(-6)	3.3(-2)
¹⁴⁴ Ce	4.7(-1)	4.7(-8)	1.0(-3)
¹⁵⁴ Eu	7.5(-3)	7.5(-10)	1.6(-5)

^a Releases to White Oak Creek of nonradioactive chemicals, such as nitric acid, ammonium hydroxide, and formaldehyde, used in the gel-sphere-pac process, are estimated to total less than 1 g/week.

^b Assume: 40-h operational week; average flow in White Oak Creek, 317 liters/s.

^c Uranium has a curie-percent composition of ²³⁴U, 59.8; ²³⁵U, 1.2; ²³⁶U, 17.5; ²³⁸U, 21.5.

^d 2.6(-5) means 2.6×10^{-5} , etc.

^e Plutonium has a curie-percent composition of ²³⁸Pu, 1.8; ²³⁹Pu, 0.3; ²⁴⁰Pu, 0.4; ²⁴¹Pu, 97.6; ²⁴²Pu, 0.1.

^f Curium has a curie-percent composition of ²⁴²Cm, 1; ²⁴⁴Cm, 99.

Table 2.6. Weekly operational releases^a to White Oak Creek from ²³³U-thorium gel-sphere-pac fuel pin preparation process

Major radionuclides	Discharge to ILW System (Ci)	Release to White Oak Creek (Ci)	Concentration ^b in White Oak Creek (pCi/liter)
Alpha emitters			
²²⁸ Th	3.5(-7) ^c	3.5(-14)	7.7(-10)
²³² Th	1.8(-6)	1.8(-13)	3.9(-9)
²³² U	1.1(-2)	1.1(-9)	2.4(-5)
²³³ U	2.1(-2)	2.1(-9)	4.6(-5)
²³⁹ Pu	2.6(-6)	2.6(-13)	5.7(-9)
Beta and gamma emitters			
⁶⁰ Co	1.0(0)	1.0(-7)	2.2(-3)

^a Releases to White Oak Creek of nonradioactive chemicals, such as nitric acid, ammonium hydroxide, and formaldehyde, used in the gel-sphere-pac process, are estimated to total less than 1 g/week.

^b Assume 40-h operational week; average flow in White Oak Creek 317 liters/s.

^c 3.5(-7) means 3.5×10^{-7} , etc.

Table 2.7. Burial ground wastes, generated weekly, from uranium plutonium gel-sphere-pac fuel pin preparation process

Material	Amount
Air filters, Ci	
U ^a	3.7(-5) ^b
Pu ^c	5.9(1)
Cm ^d	1.4(-3)
⁶⁰ Co	1.4
⁹⁵ Zr	7.1(-1)
⁹⁵ Nb	4.9(-1)
¹⁰³ Ru	3.9(-1)
¹⁰⁶ Ru	1.8
¹³⁴ Cs	1.3(-3)
¹³⁷ Cs	6.6(-4)
¹⁴⁴ Ce	1.1(-1)
¹⁵⁴ Eu	1.8(-3)
Trichloroethylene, kg	2.9
Vermiculite (absorber), kg	73
Urea-formaldehyde plastic (encasement), kg	61

^aUranium has a curie-percent composition of ²³⁴U, 59.8; ²³⁵U, 1.2; ²³⁶U, 17.5; ²³⁸U, 21.5.

^b3.7(-5) means 3.7×10^{-5} , etc.

^cPlutonium has a curie-percent composition of ²³⁸Pu, 1.8; ²³⁹Pu, 0.3; ²⁴⁰Pu, 0.4; ²⁴¹Pu, 97.5; ²⁴²Pu, 0.1.

^dCurium has a curie-percent composition of ²⁴²Cm, 1; ²⁴⁴Cm, 99.

Table 2.8. Burial ground wastes, generated weekly, from ²³³U-uranium gel-sphere-pac fuel pin preparation process

Material	Amount
Air filters, Ci	
²²⁸ Th	5.0(-7) ^a
²³² Th	2.8(-6)
²³² U	1.5(-2)
²³³ U	2.9(-2)
²³⁹ Pu	3.7(-8)
⁶⁰ Co	1.5(0)
Trichloroethylene, kg	2.9
Vermiculite (absorber), kg	73
Urea-formaldehyde plastic (encasement), kg	61

^a5.0(-7) means 5.0×10^{-7} , etc.

Solid waste source terms. The gel-sphere-pac material disposed of by shallow land burial consists of the organic waste mentioned above and the contaminated air filters used in cleaning the combustible and hot-off-gas streams (see Appendix A). The amount of radioactivity collected by the air filters and the amount of waste trichloroethylene generated each week are given in Table 2.7 and 2.8. The air filters, when changed, are bagged in sealed plastic for transport to and disposal in the burial grounds. If radiation levels are high (over 200 mr/h)

the bagged filters are also enclosed in wooden boxes and shielded during transport. The wooden boxes are then placed in the ground. The contaminated waste trichloroethylene is absorbed on vermiculite, encased in plastic, and buried. Rejected fuel pin hardware and failed equipment, which are expected to be mostly TRU-contaminated, will be compacted into stainless steel drums and placed in retrievable storage at the ORNL solid-waste-storage-area.

2.2.3.2 Sphere-cal fuel pin fabrication

The sphere-cal process, as seen in the functional diagram (Fig. 2.4), is an alternative process (option 1) to the gel-sphere-pac process, which is described in Sect. 2.2.3.1 and Appendix A. The initial sphere preparation steps and the final pin inspection and welding steps are the same for both processes. After the debonding step (see Fig. 2.4), the microspheres are treated differently through the pin loading step, after which the processes are again the same. A detailed description of those steps of the sphere-cal process which differ from the gel-sphere-pac process is given in greater detail in Appendix B.

Environmental source terms

The environmental releases from sphere-cal and gel-sphere-pac follow similar paths. The radioactivity released to the environment from the base case, gel-sphere-pac, has been presented in Tables 2.3-2.8. A comparison of the flow sheets in Appendixes A and B shows the amount of radionuclides released to the environment from the sphere-cal process is 80 to 85% of that from the gel-sphere-pac process for both uranium-plutonium and ^{233}U -thorium fuel types. The quantities released from sphere-cal are given in Table 2.9. The amounts of radionuclides

Table 2.9. Weekly operational releases of materials to the environment from the sphere-cal fuel pin preparation process.

Material	Uranium-plutonium fuel		²³³ U-thorium fuel	
	7911 stack	7930 standpipe	7911 stack	7930 standpipe
Release to atmosphere				
Radionuclides	0.8 times values in Table 2.3	0.8 times values in Table 2.3	0.8 times values in Table 2.4	0.8 times values in Table 2.4
Nonradioactive gases, liters				
Water		3		3
Ammonia		5		2
Hydrogen		3,100		350
Argon		86,000		28,000
Release to White Oak Creek				
Material	Uranium-plutonium fuel		²³³ U-thorium fuel	
Radionuclides and other	0.8 times values in Table 2.5		0.8 times values in Table 2.6	
Material to burial grounds				
Material	Uranium-plutonium fuel		²³³ U-thorium fuel	
Radionuclides (air filters)	0.8 times values in Table 2.7		0.8 times values in Table 2.8	
Trichloroethylene, and other	Same as Table 2.7		Same as Table 2.8	

released are presented as fractions of the gel-sphere-pac case. The compositions of the non-radioactive gaseous components are given, as they do not conform to a simple relationship with the corresponding gel-sphere-pac process.

The 80-85% factor results from an assumption that the process line for forming the coarse microspheres will be sized to handle 10 kg of heavy metal per week in all cases. In the gel-sphere-pac case, all the input to the coarse microsphere forming line consists of reprocessed fissile heavy metal containing most of the radionuclides of concern. Those coarse heavy-metal microspheres are later combined with additional fertile fine microspheres to form the final fuel. The final gel-sphere-pac fuel is about 15-20% fertile fines and 80-85% coarse fissile microspheres. In the sphere-cal case, the fertile material that is in the fine microspheres of the gel-sphere-pac fuel must be combined with the coarse microspheres at the start. The input to the microsphere forming line in the sphere-cal case is, therefore, 80-85% reprocessed fissile heavy metal and 15-20% fertile material. (These figures refer to the fuel only, not any fertile blanket material provided for a breeder fuel pin.)

2.2.3.3 HTGR green fuel rod fabrication

The HTGR green fuel rod fabrication process is a second alternative to the gel-sphere-pac process, which was described in Sect. 2.2.3.1 and Appendix A. The HTGR green fuel rod fabrication process (option 2, Fig. 2.4) branches off from the gel-sphere-pac process after the microsphere sintering step. The microspheres are given four coatings — two carbon coatings, a silicon carbide coating, and a final carbon coating. Green fuel rods are then molded, by manual operation, from a blend of the coated particles, fertile particles, graphite shim particles, and a pitch binder.

The processing steps unique to option 2 are described in greater detail, together with flow sheets, in Appendix C.

Environmental source terms

The quantities of materials released to the environment from the HTGR green fuel rod fabrication process are shown in Table 2.10. The quantities of radionuclides are presented as multiples of the base case (gel-sphere-pac) source terms, which are given in Tables 2.3-2.8. A step-by-step comparison may be made by consulting Appendixes A and C. Radioactive gaseous releases to the atmosphere from the HTGR green fuel rod and gel-sphere-pac processes are the same. Aqueous releases to White Oak Creek are 10% greater for the HTGR green fuel rod process than for the gel-sphere-pac process. The biggest difference between the two processes is for disposal by burial, where the quantities of radionuclides sent to the burial grounds from the HTGR green fuel rod process are up to 1.7 times those from the gel-sphere-pac process. The larger amount from the HTGR green fuel rod process results from the particulates scrubbed from the coating furnace off-gas stream by perchloroethylene (see Appendix C). Spent perchloroethylene is absorbed on vermiculite, encased in plastic, and buried. The amounts of radioactivity on the air filters are essentially the same in the two processes.

2.3 POTENTIAL EFFECTS OF ACCIDENTS

A preliminary hazards analysis for the HFEL facility^{6,7} was performed in which potential accidents were identified and evaluated with respect to their effects, consequences, and safety-related concerns. The categories of hazardous events that were considered consist of

Table 2.10. Weekly operational releases of material to the environment from the HTGR green fuel rod fabrication process

Material	Uranium-plutonium fuel		²³³ U-thorium fuel	
	7911 stack	7930 standpipe	7911 stack	7930 standpipe
Release to atmosphere				
Radionuclides	Same as Table 2.3	Same as Table 2.3	Same as Table 2.4	Same as Table 2.4
Nonradioactive gases, liters				
Water		15		10
Ammonia		6		2
Argon		340,000		300,000
Helium		34,000		34,000
Hydrogen		35,000		33,000
Acetylene		570		570
Propene		3,500		3,500
Perchloroethylene		64		64
Methyltrichlorosilane		2		2
Hydrogen chloride		16		16
Release to White Oak Creek				
Material	Uranium-plutonium fuel		²³³ U-thorium fuel	
Radionuclides and other	1.1 times values in Table 2.5		1.1 times values in Table 2.6	
Material to burial grounds				
Material	Uranium-plutonium fuel		²³³ U-thorium fuel	
Radionuclides (air filters and perchloroethylene scrubber)	1.7 times values in Table 2.7		1.7 times values in Table 2.8	
Trichloroethylene, kg	3		3	
Perchloroethylene, kg	230		230	
Vermiculite (absorber), kg	5900		5900	
Urea-formaldehyde plastic (encasement), kg	4900		4900	

natural phenomena, criticality, fire, explosion, and handling and transportation accidents. Possible causes of each of these events were identified and evaluated.

Standard techniques in the nuclear industry for accident hazard protection have been utilized. The conceptual design criteria require the HFEL to withstand 250 km/h wind loading. Design provisions have been made to modify the building structure to prevent excessive damage from tornados and earthquakes. Above the third floor, block walls are to be replaced with wall release panels. These panels will prevent potential damage to the hot-cell roofs from falling debris and to the building frame, thereby preventing failure of the overhead crane support.

Criticality events were considered in the original facility design² and are extremely unlikely because of the small quantities of fissile material in process and use of geometric safe design.

Fire hazards are not a serious threat to the facility. In-cell fires are readily controllable by an automatic Halon system. In-cell inventories of flammable materials are maintained at the smallest quantity needed. Operating areas are protected by an automatic sprinkler system. Fires in the operating areas present little hazard to the containment capabilities of the hot cells.

Explosion hazards are safely accommodated by limiting the explosion potential to less than that for which the facility was originally designed.

Off-site handling and transportation hazards will be controlled through a combination of administrative procedures and the use of shipping containers (licensed by the Department of Transportation and the Department of Energy) specifically designed to withstand harsh accident environments. No environments more severe than those considered in the container design are potentially possible in HFEL use.

2.4 ALTERNATIVES

Three alternatives to proceeding with the development of the HFEL are (1) relocation of the project site, (2) postponement of the current schedule, and (3) project cancellation. Variations in unit processes and mass flows are considered part of development planning and are not addressed in this report.

2.4.1 Relocation

The facility chosen should have generic fuel fabrication capabilities and specifically should be able to accommodate the conceptual design processes proposed. These processes are (1) fabrication of gel microspheres, (2) fabrication of sphere-pac fuel pins, (3) fabrication of sphere-cal (pellet) fuel pins, and (4) HTGR microsphere coating and rod molding. The HFEL has the above capabilities, with construction activities being limited to alterations to the existing Thorium-Uranium Recycle Facility.

Relocation to another site would require that the new facility meet the above requirements. As no other facility is presently available, a new facility would have to be constructed. Environmental impacts would be greater at a new site because in addition to the operational impacts there would be impacts from construction activities. The environmental impacts from construction would be greater than the operational impacts. Compared with the HFEL, a new facility would cost more and would require a longer period of time to become operational.

2.4.2 Postponement

The project has been delayed one year by national budgetary problems. Any further delay would jeopardize achieving a technical readiness, in the near future, on a range of promising fuel-cycle options for application within a short lead time.

2.4.3 Cancellation

The "no action" alternative of cancellation of the HFEL would be counterproductive to the objective of achieving a national readiness for possible application of proliferation-resistant fuel-cycle options. Cancellation would eliminate Hot Engineering Test Facility data and jeopardize the successful timely completion of the National Program Plan.

REFERENCES FOR SECTION 2

1. Department of Energy, *Support Facility Conceptual Design Report for Hot Fuels Engineering Laboratory*, X-OE-91, vol. I, prepared by Union Carbide Corporation — Nuclear Division, Oak Ridge, Tenn. and The Ralph M. Parsons Company, Pasadena, California, Apr. 2, 1979.
2. J. W. Anderson, S. E. Bolt, and J. M. Chandler, *Safety Analysis for the Thorium-Uranium Recycle Facility*, ORNL-4278, Oak Ridge National Laboratory, Oak Ridge, Tenn., May 1979.
3. Energy Research and Development Administration, *Conceptual Design Report Support Facility for HTGR Fuel Recycle Hot Engineering Test*, Oak Ridge, Tenn., X-OE-41, vol. II, prepared by Union Carbide Corporation — Nuclear Division, Oak Ridge, Tenn. and The Ralph M. Parsons Company, Pasadena, Calif., June 1977.
4. R. E. Lampton, R. A. Robinson, and H. O. Weeren, *Conceptual Design Report New Hydrofracture Facility*, ORNL/TM-4826, Oak Ridge National Laboratory, Oak Ridge, Tenn., July 1975.
5. H. O. Weeren, *An Evaluation of Waste Disposal by Shale Fracturing*, ORNL/TM-5209, Oak Ridge National Laboratory, Oak Ridge, Tenn., February 1976.
6. Department of Energy, *Hot Fuels Engineering Laboratory Preliminary Hazards Analysis*, Document X-OE-80, prepared by Los Alamos Technical Associates, Inc., Los Alamos, N.M. under subcontract from Oak Ridge National Laboratory, Oak Ridge, Tenn., Sept. 1978.
7. Department of Energy, *Hot Fuels Engineering Laboratory Hazard Assessment and Action Plan*, X-OE-81, prepared by ORNL, September 1978.

3. CHARACTERIZATION OF THE EXISTING ENVIRONMENT

3.1 SITE LOCATION AND LAYOUT

The proposed Hot Fuels Engineering Laboratory (HFEL) will be housed in existing buildings at Oak Ridge National Laboratory in Oak Ridge, Tennessee.

3.1.1 East Tennessee and Oak Ridge area

The city of Oak Ridge lies in an area of hills and valleys northwest of the Great Smoky Mountains and southeast of the Cumberland Mountains in the eastern part of the state. Oak Ridge National Laboratory (ORNL) is located in a Department of Energy (DOE) reservation and lies approximately 13 km southwest of the Federal Building in Oak Ridge. Figure 3.1 shows its location in Tennessee and its relation to surrounding communities. The DOE reservation is in a rural setting and is bounded by the Clinch River on its eastern, southern, and western borders.

The total population of the five nearest cities (25-km radius) amounts to approximately 50,000 people. Knoxville, the nearest major metropolitan area (about 175,000 people), is located 32 km east of ORNL. According to the 1970 Federal census, the five surrounding counties have a combined population of 413,000.

The area to the north of Oak Ridge is mountainous and sparsely settled, and portions of the land are used for underground and strip coal mining.

Three prominent TVA facilities — two coal-fired steam plants (Kingston and Bull Run) and a hydroelectric generating station (Melton Hill Dam) — are operating in the area.

Four DOE plant complexes are located on the reservation (Fig. 3.2):

1. Y-12 Plant (Y-12),
2. Oak Ridge Gaseous Diffusion Plant (ORGDP),
3. Comparative Animal Research Laboratory (CARL),
4. Oak Ridge National Laboratory (ORNL).

The Y-12 Plant (345 ha) is located on the eastern boundary of the reservation. The plant employs approximately 4800 people and functions mainly in the design and production of nuclear weapon components.

ORGDP (700 ha) employs approximately 6300 people. Located in the northwest portion of the DOE reservation, it functions primarily as a facility for the enrichment of uranium hexafluoride for use in commercial light-water reactors and nuclear weaponry.

CARL (a facility operated by the University of Tennessee for DOE) uses several areas of the DOE reservation for research on mammalian metabolism and the toxic effects of energy-related activities on mammals. Specific lands are designated to support this research program as the needs arise.

Fig. 3.1. Area of the Department of Energy reservation showing the three plants (K-25, ORNL, and Y-12), the city of Oak Ridge, and the surrounding communities.

3.1.2 ORNL

Oak Ridge National Laboratory, centrally located on the southern border of the reservation, is the main research laboratory on the reservation. ORNL's facilities include nuclear reactors (research), chemical pilot plants (related to coal conversion technology, etc.), radioisotope production facilities, and research facilities in physics, chemistry, and the environmental sciences. Historically, reactor technology has been a major programmatic effort at ORNL, and the present program emphasizes the development and evaluation of two advanced reactor types and fuel cycles associated with them: the liquid-metal-cooled fast breeder reactor (LMFBR) and the high-temperature gas-cooled reactor (HTGR).

The Oak Ridge National Laboratory lies in a verdant valley that runs approximately in an east-west direction (Fig. 3.3). Although the valley floor is highly developed within the main Laboratory area, the surrounding terrain to the east and west is wooded. A stream, White Oak Creek, passes to the south of the developed area and leaves the valley through a gap in the hills to the southwest.

Fig. 3.2. Map showing the boundaries of the four plant sites and the city of Oak Ridge.

Fig. 3.3. Topographic map of Oak Ridge National Laboratory.

From the eastern approach, the first buildings are a complex of warehouses and shops (Fig. 3.3). The adjacent red-brick buildings beside a small lake house the ORNL accelerators. A short distance further, the principal entry to the Laboratory (East Portal) is on the left. At this point, the road goes north and around a wooded hill that essentially obscures the Laboratory from view; a gap in the hill provides a glimpse of the facilities. Further on, a drive turns left to the West Portal, which was the principal entry when the Laboratory was first built. From this point a street, Central Avenue, bisects the Laboratory area and extends from the West Portal to the East Portal.

In the area between the East and West Portals, the buildings are of both wartime and recent construction, about the same number of each. The eastern portion of the Laboratory, generally well landscaped, consists of modern brick-faced buildings. The facilities in the western portion of the Laboratory are predominantly of the early construction. Many, however, have been renovated to improve their appearance and to extend their useful lives.

The Engineering Division Building, a greenhouse complex and aquatic facility, and the Environmental Sciences Division Building are west of First Street and the West Portal.

South through a gap in Haw Ridge within the next valley, roads extend east and west. Lagoon Road goes west to areas used principally for waste disposal. Melton Valley Drive goes east past two sites used in the past for demonstration reactor experiments. Just beyond the second site is the entry to relatively modern facilities including the High-Flux Isotope Reactor and two process facilities, one for transuranium-element separation and the other for fuel-reprocessing development. This last building is to house the Hot Fuels Engineering Laboratory.

Further south in Melton Valley and somewhat isolated are two research reactors. One is for experimentation with radiation shielding; the other is devoted to experiments in health physics.

The Oak Ridge National Laboratory covers a broad area and is somewhat dispersed. This dispersal permits the accommodation of a variety of experimental programs that require isolation. The natural areas beyond the central area are also used for research programs of ecology and forestry. ORNL employs approximately 5000 people.

3.1.3 HFEL

The proposed Hot Fuels Engineering Laboratory will be contained in Building 7930 (see Sect. 2.2.1), which is located in Melton Valley (Fig. 3.3). The building is commonly known as TURF (Thorium-Uranium Recycle Facility) and has not been in use recently. It is constructed of structural steel, reinforced concrete, and masonry. Perimeter walls are of reinforced concrete block. The area surrounding the facility is primarily wooded (Fig. 2.1).

3.2 TOPOGRAPHY

The area comprising the DOE reservation is dominated by a series of ridges and valleys formed during Early Cambrian to Early Mississippian times by the action of erosion on severely faulted and folded rocks.

The ridges of the more resistant sandstone, cherty dolomite, and shale run parallel in a northeast-to-southwest direction. Figure 3.3 is a topographic map of the area around ORNL. Altitudes of the ridges and valleys adjacent to the facility extend from 226 to 415 m above mean sea level, providing a maximum relief of 183 m.

3.3 GEOLOGY

3.3.1 Stratigraphy

The HFEL facility is located in the Valley and Ridge Province of the Appalachian Highlands physiographic division of the eastern United States. The proximity of the site to the various physiographic provinces within the Appalachian Highlands is shown in Fig. 3.4. As the name Appalachian Highlands implies, the area is characterized by rugged terrain that varies from rolling hills to mountains. Within 300 km of the site, the physiographic provinces include Interior Low Plateaus, Appalachian Plateaus, Valley and Ridge, Blue Ridge, and Piedmont.

Different layers of Paleozoic sedimentary rock, primarily limestone, dolomite, and shale, comprise the ridges and valleys of the area. The four major bedrock types are Rome, Conasauga, Knox, and Chickamauga.

The Rome formation is a generally well-cemented sandstone with a shaly fine grain. It has a relatively low ability to transmit groundwater because of the presence of unenlarged fractures.

Fig. 3.4. Regional physiographic map of the site of the Hot Fuels Engineering Laboratory at Oak Ridge National Laboratory. Source: Project Management Corporation and the Tennessee Valley Authority, *Clinch River Breeder Reactor Plant Environmental Report*, vol. 1, Construction Permit Stage, Docket No. 50-537, issued April 7, 1975, p. 2.4-23.

The Conasauga group consists of thin limestone units interbedded with silty and slightly calcareous shale; fractures are evenly distributed. Permeability is associated with weathering changes of the rock above and below the water table. A more uniform flow of groundwater occurs here than in the other formations.

The Knox group primarily consists of thick beds of dolomite and limestone; the permeability and porosity of the formation are unevenly distributed. As a result, there have been water localizations from fracturing and solution by groundwater movement in this formation.

The Chickamauga limestone is composed of thin beds of shaly limestone and shale. Porosity is low, and fractures have been enlarged by solution, although not as extensively as in the cavernous Knox group. Such fractures and solution channels permit the free movement of groundwater through a network of channels.

Table 3.1 lists the principal bedrock formations in the Oak Ridge area.

Table 3.1. Generalized geologic section of the bedrock formations in the Oak Ridge Area

System	Group	Formation	"Member" or Unit	Thickness (feet)	Characteristics of Rocks
Mississippian	?	Ft. Payne "chart"			Impure limestone and calcareous siltstone, with much chert
		Chattanooga shale			Shale, black, fissile
Devonian					
Silurian	Rockwood group	Brassfield		1000+	Shale, sandy shale, sandstone; calcareous; red, drab, brown
		Sequatchie			
Ordovician	Chickamauga group		? H	300+	Limestone, shaly limestone, calcareous siltstone, and shale; mostly gray, partly maroon; with cherty zones in basal portions
			G	300	
			F	25	
			E	380	
			D	160	
			C	115	
			B	215	
			A	240	
	Knox group			2600	Dolomitic limestone; light to dark gray; with prominent chert zones
Cambrian	Conasauga group	Maynardsville limestone		1500	Shale; gray, olive, drab, brown; with beds of limestone in upper part
		Conasauga shale			
		Pumpkin valley			
		Rome formation		1000+	Sandstone and shale; variegated with brilliant yellow, brown, red, maroon, olive-green; with dolomitic limestone lenses

Source: P. B. Stockdale, *Geologic Conditions at the Oak Ridge National Laboratory (X-10) Area Relevant to the Disposal of Radioactive Waste*, ORO-58, Oak Ridge Operations, Oak Ridge, Tenn., Aug. 1, 1951, Plate 11.

To convert feet to meters, multiply by 0.3048.

3.3.2 Seismology

Two major thrust faults, the Copper Creek and the Whiteoak Mountain, are recognized in the area. Both are traceable for a distance greater than 150 km within the Valley and Ridge province¹ and are shown in Fig. 3.5, which is a fault map of the vicinity. In both faults the Middle Cambrian Rome formation is thrust over the Middle Ordovician Chickamauga limestone. The Copper Creek fault occurs along the northwestern side of Haw Ridge and extends northeast across Tennessee. Further to the north is Whiteoak Mountain fault, which lies on the northwestern side of Pine

Fig. 3.5. Fault map of Oak Ridge area.

Ridge and can be traced southwest across Tennessee. The Pilot Knob syncline is a northeast extension of the Whiteoak Mountain fault in East Fork Ridge. Numerous secondary tectonic displacements have also occurred in the area.²

Since the youngest stratigraphic units mapped in the Valley and Ridge province of southern Appalachia are of Pennsylvanian age, geologists believe that all the structural features of the primary Appalachian system were formed by the end of the Paleozoic era during what is now called the Appalachian Revolution. Although numerous faults exist within the area, they all originated long ago during that orogenic period; apparently, major tectonic activity ceased completely thereafter. No physiographic evidence indicating tectonic activity, such as stream offsets, displacement of alluvial deposits, or dislocations of Plio-Pleistocene terrace materials, has been observed along any of these thrust-fault areas. Consequently, there is no reason to expect current or future translocations of these tectonic relics.^{1,3,4}

Recent seismic events that were capable of producing a shock in the Oak Ridge area and that have been recorded in the literature since 1800 are listed in Table 3.2. Data for the older earthquake incidents are largely estimates extrapolated from nonspecific newspaper reports. In addition, these 19th-century records generally show a definite bias toward earthquakes of considerable intensity, an attitude that reflects the inherent limitations of intensity measurements during that period. The inability to record low-intensity earthquakes also explains the fewer tectonic incidents recorded in the earlier time interval.

Table 3.2. Annotated list of earthquakes that have affected the Oak Ridge Reservation or the eastern Tennessee vicinity

Date	Geodetic coordinates		Epicenter area	Maximum MM intensity at epicenter	Estimated MM intensity at Oak Ridge	Notes
	°N	°W				
1811, Dec. 16	36.6	89.6	New Madrid, Mo.	XII	V-VI	Strongest shocks of a great series collectively known as the New Madrid Earthquake. Topographic changes effected over an area of 3000 to 5000 sq mile in Mississippi Valley.
1812, Jan. 23	36.6	89.6	New Madrid, Mo.	XII	V-VI	
Feb. 7	36.6	89.6	New Madrid, Mo.	XII	V-VI	
1843, Jan. 4	35.2	90.0	Western Tennessee	VIII	III-IV	Shock felt over 12 states, including the entire Tennessee Valley.
1844, Nov. 28	36.0	84.0	Knoxville, Tenn.	VI	V	25 mi from Oak Ridge area.
1861, Aug. 31	36.6	78.5	Virginia	VI	III-IV	Described as "heavy shock" in the Oak Ridge area.
1886, Aug. 31	32.9	80.0	Charleston, S.C.	IX-X	V-VI	The Great Charleston Earthquake felt over the entire eastern U.S.
1895, Oct. 31	37.0	89.4	Charleston, Mo.	XI	III-IV	Shock felt over 23 states, including the entire Tennessee Valley.
1897, May 31	37.3	80.7	Giles County, Va.	VII	III-IV	Shock felt throughout east Tennessee. Heaviest shock in historic time in southern Appalachia.
1902, May 29	35.1	85.3	Chattanooga, Tenn.	V	?	Not reported to have been felt in the Oak Ridge area.
Oct. 18	35.0	85.3	Chattanooga, Tenn.	V	?	Not reported to have been felt in the Oak Ridge area.
1904, Mar. 4	35.7	83.5	Maryville, Tenn.	V	II-III	Low intensity except at epicenter.
1905, Jan. 27	34.0	86.0	Gadsden, Ala.	VII	II	Large "felt" area, but probably very low intensity shock.
1913, Mar. 28	36.2	83.7	Strawberry Plains, Tenn.	VII	V-VI	One of the strongest shocks in southern Appalachia.
Apr. 17	35.3	84.2	Ducktown, Tenn.	V	?	Not reported to have been felt in the Oak Ridge area.
1914, Jan. 23	35.3	84.2	Southeastern Tennessee	V	?	Only felt reports are from the epicenter, so probably local.
1916, Feb. 21	35.5	82.5	Asheville, N.C.	VI	III-IV	Felt over whole state of Tennessee, especially mountains of east Tennessee.
Oct. 18	33.5	86.2	Easonville, Ala.	VII	III	Felt over seven-state area, but only light shock in Oak Ridge.
1918, June 21	36.0	84.1	Lenoir City, Tenn.	V	IV	15 mi from Oak Ridge area.
1920, Dec. 14	36.9	85.0	Rockwood, Tenn.	V	III	35 mi from Oak Ridge area.
1921, Dec. 15	35.8	84.6	Kingston, Tenn.	V	III-IV	Shock of "considerable intensity" only 15 mi from Oak Ridge area.
1924, Oct. 20	35.0	82.6	Pickens County, S.C.	V	II	Large felt area, but little effect in eastern Tennessee.
1927, Oct. 8	35.0	85.3	Chattanooga, Tenn.	IV-V	II	Not reported to have been felt in the Oak Ridge area.
1928, Nov. 2	35.8	82.8	Madison County, N.C.	VII	III	Large felt area, including all of eastern Tennessee.
1930, Aug. 30	35.9	84.4	Kingston, Tenn.	V	V	5 mi northwest of Oak Ridge Reservation.
1938, Mar. 31	35.6	83.6	Little Tennessee River Basin	III	I-III	Centered in mountains and felt widely in eastern Tennessee.
1940, Oct. 19	35.0	85.0	Chattanooga, Tenn.	V	?	Not reported to have been felt in the Oak Ridge area.
1941, Sept. 8	35.0	85.3	Chattanooga, Tenn.	IV-V	?	Not reported to have been felt in the Oak Ridge area.
1945, June 14	35.0	84.5	Cleveland, Tenn.	V	II	Felt area over southeast Tennessee and northwest Georgia.

Table 3.2 (continued)

Date	Geodetic coordinates		Epicenter area	Maximum MM intensity at epicenter	Estimated MM intensity at Oak Ridge	Notes
	°N	°W				
1946, Apr. 6	35.2	84.9	Cleveland, Tenn.	III	?	No reports of shock outside of the city.
1947, Dec. 27	35.0	85.3	Chattanooga, Tenn.	IV	?	Not reported to have been felt in the Oak Ridge area.
1954, Jan. 1	36.6	83.7	Knoxville, Tenn.	V-VI	IV-V	Large shock area including all of eastern Tennessee; no damage at Oak Ridge.
Jan. 22	35.4	84.4	McMinn County, Tenn.	V	?	No reports of shock outside of the county.
1956, Sept. 7	35.5	84.0	Corbin, Ky.	VI	IV-V	Two shocks, 14 min apart, felt over most of southern Appalachia.
1957, June 23	35.9	84.3	Knox County, Tenn.	V	IV	5 mi from Oak Ridge area.
1959, June 12	35.3	84.3	Tellico Plains, Tenn.	IV	II-III	Widely felt over eastern Tennessee and western North Carolina.
1960, Apr. 15	35.8	83.9	Knoxville, Tenn.	V	IV	20 mi from Oak Ridge area.
1968, Nov. 9	38.0	88.5	Southern Illinois	VII	II-III	Felt over 400,000-sq mile area including 23 states and areas of Canada
1969, July 3	36.1	83.7	Knoxville, Tenn.	V	III-IV	30 mi from Oak Ridge area.
Nov. 19	37.4	81.0	Southern West Virginia	VI	II-III	Large felt area but small intensity.
1971, July 12	35.9	84.3	Knoxville-Oak Ridge, Tenn.	III-IV	III-IV	Shock felt with full intensity in Oak Ridge area; no personal injuries or property damage reported.
1973, Oct. 5	35.5	83.7	Maryville, Tenn.	IV-V	III-IV	25 mi from Oak Ridge area.
Nov. 3	35.5	83.7	Maryville, Tenn.	V-VI	IV-V	25 mi from Oak Ridge area.
1975, Feb. 10	36.1	83.6	Knoxville, Tenn.	?	?	Not reported to be felt in Oak Ridge, 60 mi from Oak Ridge
May 2	36.07	84.41	Roane Co., Tenn.	?	III	10 mi from Oak Ridge area.

Sources:

1. B. C. Moneymaker, "Earthquakes of Tennessee and Nearby Sections of Neighboring States," "Part I (1699-1850)," *J. Tenn. Acad. Sci.* 29(3): 224-233 (1954)
"Part II (1851-1900)," *J. Tenn. Acad. Sci.* 30(3): 222-223 (1955)
"Part III (1901-1925)," *J. Tenn. Acad. Sci.* 32(2): 91-105 (1957)
"Part IV (1926-1950)," *J. Tenn. Acad. Sci.* 33(3): 224-239 (1958).
2. Project Management Corporation, *Preliminary Information on Clinch River Site for LMFBR Demonstration Plant*, Aug. 23, 1972, pp. 73-82.
3. The following publications of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service (formerly, U.S. Coast and Geodetic Survey),
a. *United States Earthquakes, 1928-1935* (collected annual reports), No. COM-73-11456 (Reprint).
b. *United States Earthquakes, 1936-1940* (collected annual reports), No. COM-73-11457 (Reprint).
c. *United States Earthquakes, 1941-1945* (collected annual reports), No. COM-73-11447 (Reprint).
d. *United States Earthquakes, 1946-1972* (individual annual reports).
e. *Preliminary Determination of Epicenters, 1972* (monthly listing).
f. *Earthquake History of the United States*, Publication 41-1 (Rev. ed. through 1970), Washington, D.C., 1973, pp. 21-58.
4. The Appalachian Mountains of eastern Tennessee and western North Carolina are centers that exhibit moderate seismic activity at the frequency of one to two shocks per year. Part of this seismic area lies only 80 km east of the HFEL site and accounts for most of the seismicity native to the eastern Tennessee region.

To convert miles to kilometers, multiply by 1.609; to convert square miles to square kilometers, multiply by 2.590.

The more recent seismic records indicate that the Appalachian region extending from Chattanooga to southwestern Virginia averages one to two earthquakes per year. This seismic activity is not uniform but consists of extended periods with no shocks followed by a burst of earthquakes. The maximum shock experience in the Oak Ridge area was of intensity VI on the Modified Mercalli scale (MM) recorded on March 28, 1913.⁴ Great distant earthquakes, such as the New Madrid series of 1811 and 1812 and the great Charleston earthquake of 1886, have affected the site with intensities greater than or equal to the maximum intensity of shocks involving regions that surround the site.³ From a plot made on a map of the southeastern United States (Fig. 3.6) of the epi-

Fig. 3.6. Epicenter locations for all events in the seismic history of the Southeast Region. Source: W. C. McClain and O. H. Myers, *Seismic History and Seismicity of the Southeastern Region of the United States*, ORNL-4582, Oak Ridge National Laboratory, Oak Ridge, Tenn., June 1970, Fig. 1.

centers of earthquakes, the areas of continuing seismic activity can be identified.⁵ The following are the four areas of major current tectonic mobility:

1. The Mississippi Valley area encompasses the New Madrid region of Arkansas, Kentucky, Missouri, and Tennessee. This seismic province includes the epicenter of the great series of New Madrid earthquakes, which repeatedly attained an MM intensity of XII. This area lies more than 400 km northwest of the HFEL site. The New Madrid quakes attained an intensity of V to VI in the Oak Ridge area.
2. The Lower Wabash Valley area is located in the southern regions of Illinois and Indiana. A southern Illinois earthquake of MM intensity VII in 1968 was felt over a 1,000,000-km² area including a mild shock of intensity II to III in the Oak Ridge vicinity. The HFEL site lies more than 370 km southeast of this region of active seismicity.
3. Charleston, South Carolina, was the site of one of the greatest historic earthquakes experienced in the eastern United States. The August 31, 1886, shock of MM intensity IX was felt over the entire eastern coast and registered an intensity of V to VI in the Oak Ridge region. Recurrent seismic activity continues in this area, which is 520 km southeast of the HFEL site.
4. The Appalachian Mountains of eastern Tennessee and western North Carolina are centers that exhibit moderate seismic activity at the frequency of one to two shocks per year. Part of this seismic area lies only 80 km east of the HFEL site and accounts for most of the seismicity native to the eastern Tennessee region.

As discussed previously, no correlation has been observed between recorded earthquakes on the Oak Ridge reservation and superficial tectonic structures of the Valley and Ridge province. During historic times, the zone of relatively high seismicity in the adjacent Blue Ridge province has involved only movements of low intensity that probably represent minor adjustments of highly disturbed rock formations.⁵

Algermissen⁵ prepared a seismic-risk map of the United States (Fig. 3.7) to assist in the establishment of design requirements for buildings in various segments of the country. Seismicity ratings were based either on a historical earthquake of considerable intensity or on frequency of seismic incidences regardless of intensity. The Oak Ridge reservation lies in what Algermissen designated as seismic zone 2, which is an area of moderate activity.

Algermissen and Perkins⁶ provide probabilistic estimates for the frequency of occurrence of earthquakes of a given horizontal acceleration. It must be emphasized that their estimates apply only to foundations that are coupled to bedrock. Foundations on unconsolidated alluvium may experience up to three times as much horizontal acceleration. For foundations coupled to bedrock at any location within the southern Appalachian region (as, for example, ORNL), there is a 90% probability that the horizontal acceleration will not exceed 7% of gravity (equivalent to a Modified Mercalli intensity of VII) in a 50-year period. The equation

$$\log a = \frac{I}{3} - \frac{1}{2}$$

Fig. 3.7. Seismic risk map of the United States. Source: After S. T. Algermissen, "Seismic Risk Studies in the United States," *Proc. 4th World Conf. Earthquake Engineer*, Santiago de Chile, January 13-18, 1969, vol. 1, 1969.

is a universally recognized empirical relationship between horizontal acceleration (a) and Modified Mercalli intensity (I).⁷ Accordingly, a horizontal acceleration of 70 cm/sec² (7% of gravity) is equivalent to a Modified Mercalli intensity of VII.

Algermissen and Perkins's probabilistic estimate agrees reasonably well with the seismic history of the ORNL site. Table 3.2 lists five earthquakes in the last 165 years that produced a Modified Mercalli intensity of V to VI within the vicinity of Oak Ridge. During the same time interval, no earthquakes of Modified Mercalli intensity VII or higher were reported. Intensity VII earthquakes occur approximately one order of magnitude less frequently than intensity V to VI earthquakes. This suggests a recurrence interval on the order of 300 years for intensity VII earthquakes, an estimate that is consistent with Algermissen and Perkins's probabilistic estimate.

Damage caused by intensity VII earthquakes is not severe. Examples of damage to be expected are:⁷ (1) weak chimneys broken off at the roof line, (2) damage to weak masonry of low standards of workmanship, (3) some cracks in masonry of ordinary workmanship, (4) fall of plaster, loose bricks, and stones, and (5) damage to concrete irrigation ditches. Earthquake damage as described above is expected to recur once in approximately 300 years, or it has a 10% probability of being exceeded once within a 50-year period at ORNL.

Although the Oak Ridge area experiences a moderate level of seismic activity, no incidence of surface deformation has been documented. Earthquakes of the types that occur within the region are common throughout the world. The shocks are of normal focus — 40 to 50 km (25 to 30 miles) deep. However, hypocenters of such shocks do penetrate through bedrock to crystalline basement, since sedimentary strata extend to a depth of only 5 km (3 miles).⁸ It is highly improbable that a shock of major focus will occur in the Oak Ridge area for several thousand years.² Forces from more seismically active areas will probably be dissipated by distance. Consequently, earthquake forces have generally not been considered in the design of facilities on the Oak Ridge reservation by either DOE Oak Ridge Operations or the Tennessee Valley Authority.

3.3.3 Soil description

Since groundwater flow on the Oak Ridge reservation is described primarily by water-table conditions rather than by artesian conditions, the soils of the area play a major role in regulating water flow to the various spheres of the hydrological environment.

Despite these important hydrological considerations, a thorough investigation of the soils of the Oak Ridge reservation has not yet been completed. However, certain sections of the area have been mapped. Swann and associates⁹ completed a soil survey of Roane County, Tennessee, for the U.S. Department of Agriculture in 1942, but the survey has not been revised to conform with recent nomenclature changes. Moneymaker¹⁰ of the U.S. Soil Conservation Service is currently attempting to record the soils of Anderson County, Tennessee. Carroll¹¹ made a very general analysis of the soils of the Oak Ridge vicinity for the U.S. Geological Survey. The soils of the Walker Branch Watershed have been analyzed extensively in conjunction with a project to measure nutrient cycling within this experimental ecosystem.^{12,13} McMaster and Waller¹⁴ have described the soils of the White Oak Creek basin. Although the information from these studies is insufficient to permit the construction of a detailed soil map, the data of Swann and associates, of Moneymaker, and of Carroll have been combined and correlated to produce the general soil-association map given in Fig. 3.8.

Fig. 3.8. General soil association map of the Oak Ridge reservation.

The broad soil associations suggested in Fig. 3.8 can be subdivided further into three major soil classes — residual, colluvial, and alluvial soils. All the major soils in a given association fall within the category of upland residual soils. Residual soils are defined as those soils formed by the in-situ weathering of the rocks and minerals of the underlying geology.¹⁵ Thus, corresponding to each of the four major stratigraphic units that occur extensively in this part of the Valley and Ridge Province is an association of residual soils.

Minor soils include residual soils that have arisen from minor geological strata and also two other soil classes — colluvial and local alluvial. Colluvium is a heterogeneous deposit of rock fragments and soil material accumulated primarily through gravitational forces at the bases of comparatively steep slopes. An azonal group of soils — developed from recently deposited materials, transported mainly by water, and characterized by a weak modification of the original material by soil-forming processes — is known as alluvium.¹⁵ This group settles primarily along narrow drainageways and stream depressions. Table 3.3 indicates the percentage distribution, by geological unit and by soil class, of each soil series of the White Oak Creek basin. Similar proportions may be assumed for the remainder of the Oak Ridge reservation. Soils analogous to those described in Table 3.3 occur extensively throughout the southeastern United States in the Coastal Plains, the Piedmont, the Appalachian Plateau, and the Valley and Ridge Province.¹⁵ Such soils have developed under forests and contain an A horizon that is typically light colored and covers a tougher, clayey subsoil of red, yellow, or mottled color.¹¹ The major soils are generally silty (grain size 0.06 to 0.002 mm) rather than sandy or clayey. However, considerable clay may be present in the B horizon.^{11,14} The Knox soils contain kaolinite as their principal clay, whereas illite and vermiculite constitute the bulk of Conasauga clay.

3.4 HYDROLOGY

3.4.1 Tennessee River

All waters that drain from the Oak Ridge reservation eventually reach the Tennessee-Ohio-Mississippi water system (Fig. 3.9).^{16,17} The headwater tributaries for the Tennessee River arise from points in Virginia, North Carolina, and Georgia. Initially, the river flows generally southwestward and receives inputs from eastern Tennessee and northern Alabama before bending sharply northwest to continue a winding path across western Tennessee to the river mouth at Paducah, Kentucky. The total drainage area of 106,000 km² includes about 80% of the state of Tennessee, a major segment of northern Alabama, and regions of Kentucky, Mississippi, Georgia, Virginia, and North Carolina. Many multipurpose dams regulate flow on this river system — the Tennessee River alone is dotted with nine mainstream reservoirs from Knoxville to Paducah, Kentucky.

3.4.2 Clinch River

The Clinch River provides the immediate receptacle for waters discharged from the Oak Ridge reservation. The Clinch originates in Tazewell County, which is in the southwest corner of Virginia near the Kentucky border, 280 air kilometers northeast of Oak Ridge. The river proceeds in an approximately southwestward direction for more than 560 km before merging with the Tennessee River near Kingston at Tennessee River kilometer 912.4.¹⁸ The Clinch drainage basin encompasses an area of 11,400 km² with an average width of 30 km. It is bounded on the northwest by the Cumberland Mountains and on the southeast by the Clinch Mountains and Black Oak Ridge.

Table 3.3. Distribution of the soil series of the White Oak Creek basin by geological unit and by soil class

Geologic unit ^a	Soil series			Geologic unit by physiographic position (%)			Occurrence of upland soil series (%)
	Upland	Colluvial	Local alluvial	Upland	Colluvial	Local alluvial	
Ock ^b	Fullerton	Minvale	Emory	82	10	8	70
	Bodine	Landisburg	Greendale				5
	Claiborne						5
	Dewey						2
Och a ^c	Fullerton			100			80
	Bodine						20
Och b	Bland ^d	Bland		80	20		60
	Colbert	Colbert					20
Och d	Talbott	Leadvale	Leadvale	80	← 20 →		35
Och e	Colbert	Hamblen	Hamblen				35
Och f	Rock outcrop						15
Och g							
Och h	Sequoia	Muse ^e		80	20		15
	Litz	Jefferson ^e					25
	Rock outcrop						40
Cr ^f	Muskingum	Jefferson		90	10		60
	Lehew	Muse					25
	Hartsells						5
Eca ^g	Montevallo	Muse		85	15		60
	Litz	Jefferson					25
		Sensabaugh					
Ecb	Litz	Leadvale	Leadvale	85	← 15 →		50
	Sequoia	Muse					35
		Hamblen					
Ecc	Litz	Leadvale	Leadvale	85	← 15 →		70
	Sequoia	Hamblen					15
Ecd	Rock outcrop			90	10		75
	Litz						15
Whiteoak Creek alluvium			Hamblen Newark Dunning				
Clinch River			Nolichucky Waynesboro				

^a Refer to Fig. 3.8 for soil locations.

^b Ock denotes Knox dolomite.

^c Och denotes Chickamauga limestone, whereas subsequent letters indicate the various substrata.

^d This group also includes portions of rock outcrop, which is restricted to soils that have more than 25% of their areas covered by undissolved rock.

^e These colluvial soils originated from upland Rome formation strata.

^f Cr denotes Rome formation.

^g Ec denotes Conasauga shale, whereas subsequent letters indicate the various substrata.

Sources:

1. W. M. McMaster and H. D. Waller, *Geology and Soils of Whiteoak Creek Basin, Tennessee*, ORNL/TM-1108, Oak Ridge National Laboratory, Oak Ridge, Tenn., May 1965.

2. R. P. Sims, State Soil Scientist, Soil Conservation Service, U.S. Department of Agriculture, letter to W. O. Abbott, Oak Ridge National Laboratory, Aug. 1, 1974, regarding data of R. H. Moneymaker, U.S. Soil Conservation Officer, Anderson County, Tenn.

A dam at Clinch River kilometer 37.2 has created the Melton Hill Reservoir, which furnishes the eastern and southeastern boundary of the Oak Ridge reservation. This reservoir extends 71 river kilometers to Eagle Bend, which lies about 13 km above Clinton. A volume of 1.46×10^8 m³ of water is impounded at the normal maximum elevation of 242 m. The Melton Hill Dam, completed in May 1963, was constructed for power production, navigation, recreation, and some low-flow regulation, but it functions little in flood control.

Backwaters from Watts Bar Dam (impounded in 1942) on the Tennessee River define part of the southwestern and western boundaries of the DOE property. Watts Bar Dam is located at Tennessee

Fig. 3.9. Map of the Tennessee River valley and vicinity showing important dams and steam plants. Source: E. G. Struxness (Chairman) et al., Clinch River Study Steering Committee, *Comprehensive Report of the Clinch River Study*, ORNL-4035, Oak Ridge National Laboratory, Oak Ridge, Tenn., April 1967, Fig. 3-7.

River kilometer 852.4, about 61 km downstream from the mouth of the Clinch. Before Melton Hill Dam was built, Watts Bar Dam regulated flows at the Oak Ridge reservation to Clinch River kilometer 45.1. The dam's primary purposes include flood control, navigation, electric-power generation, and recreation. Minimum and maximum reservoir elevations have been established, which are based on navigation and flood-control requirements. The minimum elevation recorded to date is 223.3 m (recorded on March 20, 1945), whereas the maximum elevation was measured at 227.0 m on March 17, 1973.¹⁹ In the vicinity of the Oak Ridge reservation, the reservoir ranges in width from 90 to 180 m and in depth from 6.7 to 7.3 m at the full-pool elevation of 227 m.

3.4.3 Clinch River tributaries

The largest tributaries of the Clinch are the Powell and Emory rivers. The Powell arises southeast of the headwaters of the Clinch, flows parallel to the Clinch, receiving water from a 2420-km² area, and intersects the Clinch above Norris Dam at Clinch River kilometer 142.9. Northwest of the reservation, the Emory River drains a basin of 2240 km² before joining the Clinch at Clinch River kilometer 7.1 near Kingston.

The Oak Ridge reservation is composed of a series of limited drainage basins which small streams traverse, ultimately reaching the Clinch River. These watersheds generally fall 183 m from the ridge crests to their mouths. Brief descriptions of the major watersheds on the reservation are given below.²⁰

The White Oak Creek basin of 16.5 km² includes parts of Bethel Valley and Melton Valley (site of Building 7930). Melton Valley is also the location of ORNL's disposal areas for solid and liquid radioactive wastes. White Oak Creek flows south into Melton Valley from Bethel Valley through a gap in Haw Ridge. Elevations in the watershed range from 372 m at the crest of Chestnut Ridge to 226 m at the creek mouth at Clinch River kilometer 33.5. The primary tributary of White Oak Creek is Melton Branch, which permits flows from Haw and Copper ridges to unite with the main stream at White Oak Creek kilometer 2.5. The waters of White Oak Creek are impounded by White Oak Dam, located 1.0 km above the stream mouth. The dam is an earthen structure with a steel cofferdam and gate built as a highway fill where Whitewing Road (Tennessee State Highway 95) crosses the creek. White Oak Lake was constructed in October 1943 to regulate the dispersion of radionuclides and chemical pollutants discharged from ORNL. White Oak Lake is now a standing pool that can function as an emergency storage pond in the event of a major accidental release of contaminants.

Poplar Creek²¹ receives drainage from a 350-km² area, including the northwestern sector of the Oak Ridge reservation. The topographic relief of this basin exceeds that of all other water systems in the Oak Ridge area. Waters flow from the western half of the watershed (in the Cumberland Mountain section of the Appalachian Plateau Province) at elevations exceeding 975 m to valleys in the Valley and Ridge physiographic unit at elevations of 226 m near the mouth. The creek flows through a basin that is about 65% wooded; the remainder is farmland. Some contamination occurs from the extensive surface coal mining that has been undertaken in the Cumberland Mountain district. The creek also receives effluents from several small communities, including Oliver Springs.

The East Fork of Poplar Creek drains a 77-km² roughly rectangular watershed, which is 15 km long and 5.5 km wide and intersects Poplar Creek at Poplar Creek kilometer 8.8. The East Fork originates on Chestnut Ridge, which separates this drainage area from the White Oak Creek catch-

ment. The headwaters are collected in the Y-12 Plant area, where they receive wastes (primarily) in the form of cooling-tower blowdown, waste-stream condensate, and process cooling water. The creek then flows northwestward roughly paralleling Tennessee State Highway 62 into the residential areas of Oak Ridge.

The 12-km-long drainage basin of Bear Creek begins at the southwest boundary of Y-12. This creek meanders westward through Bear Creek valley until it reaches McNew Hollow, where it slices abruptly northwest to cross Pine Ridge and the valley that lies between McKinney Ridge and East Fork Ridge. In its course, it parallels Bear Creek Valley Road and Whitewing Road through the ridge hollow. Bear Creek then flows beyond the intersection of Whitewing Road and Oak Ridge Turnpike to join the East Fork of Poplar Creek. The catchment is about 65% wooded; the remainder consists of old fields. Although the creek does not serve as a watershed for the main site of the Y-12 Plant, drainage from the plant's waste-disposal and refuse areas are collected in this basin.

The Walker Branch Watershed is currently being used by the ORNL Environmental Sciences Division in experiments on nutrient cycling in an undisturbed ecosystem;²² consequently, it has been the subject of detailed hydrological analysis.^{23,24} The drainage basin lies 3.6 km east of the X-10 site and originates on Chestnut Ridge. Water from two catchments, a larger east fork and a smaller west fork, discharges the drainage from a 3.88-km² basin into the Clinch River at kilometer 53.1. Before the construction of the Oak Ridge facilities, about 25% of this watershed was used for agricultural purposes. However, these agricultural lands have reforested in the intervening 30 years, and the basin is presumed to represent an undisturbed ecosystem typical of the Eastern Deciduous Forest Biome of the Valley and Ridge Province.

The lower reaches of Scarboro Creek basin are included in the site of Tennessee's first arboretum, developed by the University of Tennessee's Forestry Department. To provide pooled water for certain species of trees, a series of dams has been constructed on the 2.93-km² catchment. No major records are maintained for this stream.

3.5 METEOROLOGY

3.5.1 Regional climate

Oak Ridge National Laboratory is located in a broad valley between the Cumberland Mountains northwest of the area and the Great Smoky Mountains to the southeast. These mountain ranges are oriented northeast-southwest, and the valley between is corrugated by broken ridges 90 to 150 m high parallel to the main valley. Storm tracks appear to travel from northwest to southeast; associated wind velocities are somewhat decreased by the mountains and ridges. Tornadoes rarely occur in the valley between the Cumberlands and the Smokies.²⁵ In winter the Cumberland Mountains have a moderating influence on the local climate by retarding the flow of cold air from the north and west.

Relatively warm summers and cool winters characterize continental climatic regions in the southeastern United States. Cold, dry air masses from Canada predominate in the winter. They usually undergo modification and warming as the air crosses the ridges of the Cumberlands and moves down the eastern slopes. Anticyclonic circulation of the atmosphere about the Bermuda-Azores high-pressure system results in a predominance of warm, moist air from the Gulf during the rest of the year.²⁶ For about 33 days each year, temperatures reach 32.2°C or higher, and temperatures

of -17.8°C or lower are expected one day each year. Temperatures of 0°C or lower normally occur on 82 days annually. Precipitation amounts are greatest during winter and early spring and are lowest in early autumn. A secondary precipitation maximum, associated with thundershower activity, occurs in July. The annual relative humidity averages 70%.

3.5.2 Local climate

The climate of Oak Ridge is typical of the humid southern Appalachian region. The local climate is noticeably influenced by topography.²⁷ Prevailing winds are usually either up-valley from southwest to northeast (daytime) or down-valley from northeast to southwest (nighttime).

Differences in elevation have a measurable influence on the changes in climate along a northeast-southwest axis; stations at similar elevations have similar annual mean temperature and precipitation normals. The mean area annual rainfall is approximately 136 cm and the mean temperature is 14.4°C . Precipitation is predominantly in the form of rainfall, although snowfall is occasionally a significant contributor. The annual precipitation pattern is characterized by wet winters and comparatively dry springs followed by relatively wet summers and dry autumns. July rainfall (15 cm) normally approaches that of the wet winter months, but June (8.1 cm) is as dry as the autumn months.

Intense localized weather consists mainly of severe thunderstorms in warm seasons and large-scale storms in the winter. Remnants of hurricanes, weakened by loss of moisture, occasionally affect the area. Between 1953 and 1974, 54 tornadoes occurred within the 25,000-km² site area.²⁵ There were 15 reports of hail 1.9 cm in diameter or greater and 46 reports of windstorms with speeds of 50 knots (93 km/hr) or greater within the 1° latitude-longitude square (approximately 100 x 120 km) of the site during the period 1955 through 1967. During the period 1871 through 1973, four tropical storms or hurricanes passed within 80 km of the area. Freezing precipitation can be expected about five times each year, and a severe ice storm (accumulation of 2.5 cm or more), once every five years. High air pollution potential can be expected on seven days annually.

3.5.3 Meteorology stations

There are five meteorology stations in the area. These are (1) X-10 weather station located approximately 1.6 km southeast of ORNL, (2) Oak Ridge City weather station, about 12.8 km north-northeast of the site, (3) Clinch River Breeder Reactor Plant (CRBRP) site weather station, about 8.8 km southwest of the site, (4) Oak Ridge Gaseous Diffusion Plant weather station, about 9.6 km west-northwest of the site, and (5) the Knoxville Airport weather station, about 32 km east-southeast of the site. The Knoxville Airport weather station is a first-order weather station. (First-order weather stations are usually located at major airports and are manned 24 hr a day. These stations record hourly visual observations as well as wind, temperature, dewpoint, etc. Second-order stations record and/or transmit data on physical phenomena only.) The X-10 weather station was a first-order station from 1944 to 1964. From 1964 to 1972, only wind, temperature, dewpoint, and differential temperature were recorded. The station was discontinued in December 1972. Data from the X-10 weather station, as assembled by Hilsmeier (1963),²⁸ supplemented by CRBRP and Knoxville Airport data, were used to characterize airborne radionuclide distributions in this report. Locations of area weather stations are shown in Fig. 3.10.

3.5.4 Temperature

The coldest month in the ORNL area is normally January, but differences between the mean temperatures of the three winter months of December, January, and February are comparatively small.

Fig. 3.10. Locations of weather stations near site. Source: Project Management Corporation, *Clinch River Breeder Reactor Plant Environmental Report*, vol. 1, 179 Washington St., Chicago, Ill., April 1975, p. 2.6-82.

The lowest mean monthly temperature of the winter has occurred in different years in each of the months of December, January, and February. July is usually the hottest month, but differences between the mean temperatures of the summer months of June, July, and August are also relatively small. The highest mean monthly temperature can occur in June, July, or August; the highest temperature of the year has occurred in the months of June, July, August, and September in different years. Mean temperatures of the spring and fall months progress in an orderly fashion without a secondary maximum or minimum. Temperatures of 37.8°C or higher are unusual, as are temperatures of zero or below. The average number of days between the last freeze of spring and the first freeze of fall is approximately 200. Low-elevation temperature inversions occur during approximately 56% of the hourly observations.²⁷ Fall is usually the season with the greatest number of hours of low-level inversion, with the number decreasing progressively through spring and winter to a summertime minimum. Table 3.4 presents area temperature summary data.

3.5.5 Precipitation

March is normally the wettest month and October the driest. Precipitation is heaviest from December through March when cyclonic activity is high and in July and August when convective showers occur. Regional-scale weather systems move through eastern Tennessee with irregularity. These storm systems are most frequent during December and January and cause a maximum monthly number of cloudy days and extensive precipitation. Summer storm systems are usually weaker and

Table 3.4. Temperature and precipitation — Oak Ridge Area

Station X-10									
Month	Temperature, 1945 to 1964					Precipitation, 1944 to 1964			
	Climatological standard normals 1931 to 1960			Extremes 1945 to 1964		Monthly average ^a (in.)	Monthly maximum (in.)	Monthly minimum (in.)	Maximum in 24 hour (in.)
	Mean monthly (°F)	Daily maximum (°F)	Daily minimum (°F)	Highest temperature (°F)	Lowest temperature (°F)				
December	40.4	49.4	31.3	76	-5	5.22	10.28	1.98	4.38
January	40.1	48.9	31.2	77	-8	5.24	12.37	1.11	3.96
February	41.7	51.6	31.8	77	0	5.39	10.01	1.89	3.23
Winter	40.7	50.0	31.4	77	-8	15.85			
March	48.0	58.9	37.0	87	4	5.44	9.69	2.05	3.84
April	58.2	70.0	46.3	89	24	4.14	8.54	1.25	2.39
May	66.9	79.0	54.8	94	32	3.48	7.01	0.90	2.09
Spring	57.7	69.3	46.0	94	4	13.06			
June	74.7	86.1	63.3	99	41	3.38	7.55	1.18	3.08
July	77.4	88.0	66.7	103	49	5.31	10.19	2.14	3.74
August	76.5	87.4	65.6	99	44	4.02	10.31	0.50	3.31
Summer	76.2	87.2	65.2	103	41	12.71			
September	71.1	82.0	60.2	103	33	3.59	12.84	0.21	7.75
October	60.0	72.2	47.7	91	21	2.82	6.43	0.00	2.32
November	47.6	58.6	36.5	83	4	3.49	12.00	1.01	3.20
Fall	59.6	71.3	47.6	103	4	9.90			
Annual	58.5	69.4	47.6	103	-8	51.52	12.84	0.00	7.75
Oak Ridge city office									
Climatological standard normals 1941 to 1970									
Annual	57.8	68.6	47.0	105 ^b	-9 ^b				
Knoxville vicinity									
Climatological standard normals 1941 to 1970									
Annual	59.7	69.8	49.5	104 ^c	-16 ^c				

^aClimatological standard normals — 1931 to 1960.^bMay 1947 and October 1974.^cJuly 1930 and January 1884.Source: Project Management Corporation and the Tennessee Valley Authority, *Clinch River Breeder Reactor Plant Environmental Report*, vol. 1, Construction Permit Stage, Docket No. 50-537, issued April 7, 1975, Tables 2.6-4 and 2.6-8.

To convert degrees F to degrees C, subtract 32 and multiply by 0.55; to convert inches to centimeters, multiply by 2.54.

tend to pass to the north, leaving eastern Tennessee with sunshine interspersed with thunderstorm activity. Between 50 and 60 thunderstorm days occur per year, with a peak number of storms in July.²⁷ Precipitation is highly variable; a few of the larger monthly amounts recorded in the vicinity have occurred in the normally drier fall months. Periods of 5 consecutive days without measurable precipitation occur about four or five times per year, periods of 10 consecutive dry days average one to two per year, and dry periods of more than 11 days average less than one per year. Light snow usually occurs in all months from November through March, but the total monthly snowfall is often only a trace. Snowfalls sufficiently heavy to interfere with traffic and outdoor activities occur infrequently. A summary of precipitation data for the area is presented in Table 3.4. Mean monthly precipitation averages for the Oak Ridge area are presented graphically in Fig. 3.11.

3.5.6 Glaze

Glaze (freezing rain) occurred from three to six times per year during a 28-year survey period ending in 1953. Glaze can occur during the normally colder months whenever rain falls through a very shallow layer of cold air from an overlying warm layer. Rain then freezes on contact with the ground or other objects to form a glaze. December through early March is the period with the highest frequencies of glaze storms. Based on limited periods of data collection,

Fig. 3.11. Climograph of the Oak Ridge area. Source: J. W. Curlin and D. J. Nelson, *Walker Branch Watershed Project: Objectives, Facilities, and Ecological Characteristics*, ORNL/TM-2271, Oak Ridge National Laboratory, Oak Ridge, Tenn., September 1968, p. 17. To convert degrees F to degrees C, subtract 32 and multiply by 0.55; to convert inches to centimeters, multiply by 2.54.

significant glaze storms producing glaze thicknesses of 0.6 cm or more on wires occur in eastern Tennessee on an average of once every two years. Occurrences for glaze storms in the area including the site are as follows:¹⁹

Thickness (cm)	Occurrence period (years)
0.6	2
1.2	5
1.8	10

3.5.7 Tornadoes

The site is located in an area infrequently subjected to tornadoes.¹⁹ For the purpose of comparison, Tennessee ranked 25th among all states in the number of tornadoes from 1955 to 1967. Dividing along the 86th meridian, the western half has reported three times as many tornadoes as the eastern half of the state. The Oak Ridge area has one of the lowest probabilities of tornado occurrence in the entire state. Tornado frequencies calculated by Thom for each 1°

square of latitude and longitude for the period 1953 to 1962 show the site to be situated in a 1° square with an annual frequency of 0.5. The probability that a tornado will strike any point in a particular 1° square such as the site is calculated as 3.65×10^{-5} per year; the recurrence interval is 27,400 years. Roane County itself has not recorded a tornado in the 57-year period of 1916 to 1972.

3.5.8 Local wind patterns

As previously discussed, the local area and the region experience a largely bimodal wind direction pattern that consists of up-valley and down-valley flows. The stability characteristics of these two directional channels are also nearly identical and represent the critical dispersion conditions. It is likely, however, that the similar flows are caused by differing meteorological phenomena.²⁹ The down-valley draft, identified with drainage of gravitational flow down local slopes and the broader Tennessee valley, prevails during the inversion conditions of late evening through midmorning, at which time regional pressure patterns dependent on solar inputs are very weak. However, in the daytime, up-valley flow results when the regional flows aloft become sufficiently strong to dominate over the opposing flows. Since these higher-altitude regional winds do not exert as pronounced an influence on valleys, the local valley wind regime can even maintain its structure and flow in a direction opposite to that of the regional wind. A normally quoted average wind speed for Oak Ridge of 7 km/hr is the mean value of annual measurements taken over a 16-year period at the Oak Ridge city office. Inversion conditions occur about one-third of the time throughout the year. This type of vertical temperature distribution occurs primarily as a diurnal response to radiative and convective heat transfers at the earth's surface but may be secondarily modified by both seasonal solar energy input and cloudiness. A relatively high potential for significant air pollution results, as illustrated in Fig. 3.12.

Fig. 3.12. Total number of forecast days of high meteorological potential for high air pollution in a 5-year period. Source: Project Management Corporation, *Clinch River Breeder Reactor Plant Environmental Report*, vol. 1, 179 W. Washington St., Chicago, Ill., April 1975, p. 2.6-84.

3.5.9 Wind and stability class

All-season area wind-rose data are presented in Fig. 3.13. The data were assembled from 107,000 observations taken over a period of 12-1/4 years.²⁸ Seasonal differences in the wind data are insignificant; area wind data are tabulated in Table 3.5.²⁵

Fig. 3.13. Wind-rose data, 1956-1960. Source: W. F. Hilsmeier, *Supplementary Meteorological Data for Oak Ridge*, ORO-199, Atomic Energy Commission, Division of Technical Information, Office of Technical Services, Department of Commerce, Washington, D.C., 1963. To convert miles per hour to kilometers per hour, multiply by 1.609.

Table 3.5. Monthly wind data

Month	Oak Ridge city office ^b		Knoxville airport ^c		Area station X-10 ^d		CRBRP meteorological tower ^a			
	Average speed (mph)	Prevailing direction	Average speed (mph)	Prevailing direction	Average speed (mph)	Prevailing direction	75-ft level		200-ft level	
							Average speed (mph)	Prevailing direction	Average speed (mph)	Prevailing direction
January	4.8	SW	8.2	NE	5.3	SSW	4.7	SW	8.7	SW
February	5.0	ENE	8.7	NE	6.0	SSW	7.6	WNW	8.3	SW
March	5.3	SW	9.2	NE	6.8	WSW	7.6	SW	14.3	SW
April	5.7	SW	9.3	WSW	7.0	SSW	7.6	SW	11.6	SW
May	4.5	SW	7.4	SW	6.2	NE	7.8	SW	8.4	SW
June	4.2	SW	6.7	SW	6.2	WSW	6.0	SW	8.7	SW
July	3.9	SW	6.3	WSW	4.2	SSW	7.2	SW	8.1	SW
August	3.7	E	5.7	NE	1.5	SSW	3.8	SW	4.3	SW
September	3.8	E	5.9	NE	2.9	NNE	3.1	E	3.4	ENE
October	3.6	E	5.9	NE	2.9	NNE	3.0	SW	3.6	SW
November	4.1	E	7.2	NE	3.2	N	4.7	SW	8.3	SW
December	4.5	SW	7.6	NE	4.3	NNE	4.6	WNW	6.0	ENE
Annual	4.4	SW	7.3	NE	4.7	SSW	4.9	SW	6.7	SW

^aOne-year record (102 ft, sensor elevation).

^bSixteen-year record on wind speed, 13-year record on prevailing direction.

^cThirty-one-year record on wind speed, 14-year record on prevailing direction.

^dOne-year record (102 ft, sensor elevation).

Source: Project Management Corp., *Clinch River Breeder Reactor Plant Environmental Report*, vol. 1, 179 W. Washington St., Chicago, Ill. 1975, Table 2.6-5.

To convert feet to meters, multiply by 0.3048; to convert miles per hour to kilometers per hour, multiply by 1.609.

Pasquill stability-class data for the ORNL area are summarized in Table 3.6.

A more detailed summary of wind speed and direction data has been prepared by the Atmospheric Turbulence and Diffusion Laboratory of the National Oceanic and Atmospheric Administration, Oak Ridge, Tennessee, and includes ORGDP observations over a period of 13 years, as noted in Table 3.7.²⁷ The National Oceanic and Atmospheric Administration has operated the ORGDP meteorological observation program at Oak Ridge for more than 20 years. The peak gust (wind velocity) of record was 95 km/hr during this period. Calm conditions prevailed approximately 10% of the time; partly cloudy, 25%; and cloudy, 45%.

3.6 ECOLOGY

3.6.1 Terrestrial

3.6.1.1 Overview

The Oak Ridge reservation of the Department of Energy consists of approximately 15,000 ha within the Ridge and Valley physiographic province of eastern Tennessee. The reservation was predominantly agricultural land prior to Federal acquisition in 1942 for use in the wartime Manhattan Project. With Federal ownership, the land was withdrawn from public access, and much of it was allowed to revert to natural plant cover. About 10,500 ha are managed currently for environmental research, wood-fiber production, or both.

3.6.1.2 Vegetation^{30,31}

The dominant oak-hickory association in the Ridge and Valley Province contains elements of the mixed mesophytic association commonly found in the adjacent Cumberland Mountains. Plant communities of the Oak Ridge reservation are characteristic of those found in the intermountain regions of Appalachia from the Allegheny Mountains in southern Pennsylvania to the southern extension of

Table 3.6. Pasquill stability class data for ORNL area

Pasquill stability class	Definition of class	Fraction of the year in stability class
A	Extremely unstable conditions	0.07
B	Moderately unstable conditions	0.14
C	Slightly unstable conditions	0.13
D	Neutral conditions	0.28
E	Slightly stable conditions	0.20
F	Moderately stable conditions	0.14
G	Extremely stable conditions	0.04

Source: W. F. Hilsmeier, *Supplementary Meteorological Data for Oak Ridge, ORO*, Atomic Energy Commission, Division of Technical Information, Office of Technical Services, Department of Commerce, Washington, D. C., 1963.

Table 3.7. Wind rose data — percent occurrence of wind speed for all wind directions (ORGDP weather station, 1957 to 1969)^a

Compass point direction	Wind speeds (mph)						Total
	1-3	4-7	8-12	13-19	20-24	25+	
N	1.17%	0.75%	0.42%	0.13%	0.01%	0.00%	2.49%
NNW	0.85	0.81	0.60	0.17	0.02	0.00	2.46
NW	1.01	1.37	1.67	0.78	0.14	0.01	4.99
WNW	0.53	0.88	1.23	0.70	0.11	0.02	3.47
W	0.78	1.20	1.31	0.72	0.15	0.03	4.19
WSW	0.71	1.12	0.98	0.38	0.08	0.02	3.29
SW	1.84	3.45	3.22	1.07	0.17	0.04	9.79
SSW	1.33	1.84	1.29	0.34	0.08	0.01	4.90
S	1.84	1.97	0.97	0.28	0.05	0.02	5.13
SSE	0.58	0.40	0.12	0.04	0.01	0.00	1.15
SE	1.03	0.50	0.12	0.02	0.00	0.00	1.67
ESE	0.63	0.20	0.05	0.01	0.00	0.00	0.89
E	2.18	0.80	0.26	0.06	0.01	0.00	3.30
ENE	3.07	1.44	0.51	0.11	0.01	0.00	5.14
NE	12.07	7.24	2.05	0.54	0.05	0.00	21.96
NNE	3.90	2.12	0.66	0.16	0.01	0.00	6.85

^aWind speed and frequency values are for wind blowing from the compass point direction noted.

Source: Air Resources Atmospheric Turbulence and Diffusion Laboratory (ATDL), Environmental Research Laboratories, "Daily, Monthly and Annual Climatological Data for Oak Ridge, Tn, Townsite and area stations, January 1951 — December 1971." U.S. Department of Commerce, National Oceanic and Atmospheric Administration, ATDL Contribution File G1, July 1972.

To convert miles per hour to kilometers per hour, multiply by 1.609.

the Cumberland Mountains in northern Alabama. On the reservation, the oak-hickory association is typified by extensive stands of pine, oak, and hickory as well as other hardwoods. Yellow poplar (*Liriodendron tulipifera*) often forms nearly pure stands on well-drained bottomlands and lower slopes, and willow (*Salix discolor*), sycamore (*Platanus occidentalis*), and box elder (*Acer negundo*) border streams and are dominant on poorly drained floodplains. Species more commonly found in the mixed mesophytic association, such as beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), magnolia (*Magnolia acuminata*), buckeye (*Aesculus* spp.), and basswood (*Tilia americana*) often occur in the coves and on the sheltered slopes. In addition, approximately 1740 ha of the reservation were planted in loblolly pine (*Pinus taeda*) between 1947 and 1956, and smaller areas have since been planted in loblolly pine, black walnut (*Juglans nigra*), river birch (*Betula nigra*), sycamore, and yellow poplar.

For discussion, it is convenient to group the mosaic of plant communities on the reservation into three categories, which roughly correspond to identifiable successional stages: old-field grasslands, pine forests, and hardwood forests.

Old-field grasslands

Old-field grasslands are found where land has recently been abandoned or where periodic mowing or other cultural practices maintain an early successional stage, such as under power lines and along roads. Plants found in old fields consist of annual forbs and grasses (e.g., *Ambrosia artemisiifolia*, *Digitaria sanguinalis*), biennial and perennial forbs (e.g., *Conyza canadensis*, *Oenothera* spp., *Aster* spp.), perennial grasses (*Andropogon virginicus*, *Festuca elatior*, *Panicum* spp.), and woody species (*Diospyros virginiana*, *Juniperus virginiana*, *Sassafras albidum*, *Campsis radicans*, *Rhus* spp., *Pinus* spp., and *Lonicera japonica*).

Pine forests

Both pine plantations and native seral pine forests occur on the reservation. Natural seres are dominated by Virginia pine (*Pinus virginiana*) and shortleaf pine (*P. echinata*), but the plantations are of loblolly. Loblolly pine plantations are managed (thinning and controlled burning) to minimize understory vegetation, whereas the natural seres produce an understory of native hardwoods that gradually replace the pines.

Hardwood forests

Upland hardwood forests are dominated by various oaks (*Quercus prinus*, *Q. alba*, *Q. velutina*, *Q. rubra*, *Q. coccinea*, and *Q. stellata*) and hickories (*Carya* spp.). Other hardwoods are ash (*Fraxinus* spp.), yellow poplar, red maple (*Acer rubrum*), tupelo (*Nyssa sylvatica*), beech, and dogwood (*Cornus florida*). A characteristic lowland forest occurs on floodplains and consists of cottonwood (*Populus deltoides*), sycamore, elm (*Ulmus americana*), ash, willow, sugar maple, and river birch.

Rare and endangered plants

Two plant species have recently been found on the DOE reservation which are on the *Federal Register* list of threatened or endangered plants.³² These are *Cimicifuga rubifolia* (Ranunculaceae) and *Saxifraga careyana* (Saxifragaceae). *Conradina verticillata* (Lamiaceae) has been recorded from nearby Morgan County³⁰ and could possibly occur on the reservation. Sixteen species have been identified as rare on the reservation, but all are locally abundant within the state of Tennessee.³³

3.6.1.3 Animals^{30,31}

The diversity of plant communities of the successional mosaic has made possible a rich fauna that has been intensively studied.

Fauna of upland forests

Common small mammals of upland forests include white-footed mouse (*Peromyscus leucopus*), chipmunk (*Tamias striatus*), golden mouse (*Ochrotomys nuttalli*), short-tail shrew (*Blarina brevicauda*), flying squirrel (*Glaucomys volans*), and house mouse (*Mus musculus*). The white-footed mouse is the most common small mammal, with up to 8.4 individuals per hectare. Chipmunk is the next most common, with up to 2.4 individuals per hectare.

Predators include red fox (*Vulpes fulva*), gray fox (*Urocyon cinereoargenteus*), skunk (*Mephitis mephitis*), bobcat (*Lynx rufus*), and weasel (*Mustela frenata*). There is a large deer herd (*Odocoileus virginianus*) on the reservation.

Sixty bird species, 10 amphibian species, and 19 reptilian species have been recorded for upland forests. The arthropod fauna has been extensively studied and is well known for taxonomic levels above the species.

Fauna of pine forests

Pine forests are used by fauna to a lesser extent than upland deciduous forests or old fields.³⁰ Small-mammal studies showed only low populations of three rodents. The pine warbler (*Dendroica pinus*) is the only bird species that requires pines. Reptile, amphibian, and arthropod populations may be depressed.

Fauna of old-field grasslands

Small mammals are abundant and diverse in old fields and include cotton rats (*Sigmodon hispidus*), white-footed mouse, golden mouse, rice rat (*Oryzomys palustris*), short-tail shrew, and eastern harvest mouse (*Reithrodontomys humilis*). More than 100 bird species have been recorded from reservation old fields, as have 12 amphibian species and 36 reptilian species.³⁰

Rare and endangered animals

The southern bald eagle (*Haliaeetus l. leucocephalus*) and the eastern cougar (*Felis concolor cougar*) have both been sighted on the reservation. Both are endangered.³⁴ The endangered Indiana bat (*Myotis sodalis*) has been recorded from nearby Campbell County, Tennessee, and suitable habitat exists on the reservation; none has been sighted, however. The American osprey (*Pandion haliaetus carolinensis*) is included in the Audubon Blue List³⁵ and has been seen on the reservation.

3.6.1.4 Project site

HFEL will occupy building 7930, located in what is basically an industrial setting. The building is not in close proximity to undisturbed natural ecosystems, and there are no plans to expand into any natural area.

3.6.2 Aquatic ecology

3.6.2.1 Clinch River (including Melton Hill Reservoir)

The Clinch River is the major source of water used in the Oak Ridge area. Water pumped by the Oak Ridge pumping station (at Clinch River kilometer 66.8) is delivered to ORNL, Y-12, and the city of Oak Ridge. Wastewater from ORNL is returned to the Clinch River via White Oak Creek; from Y-12, via the East Fork of Poplar Creek; and from ORGDP, directly. The section of the river primarily affected by DOE operations extends from Clinch River kilometer 66.8 on Melton Hill Reservoir to Clinch River kilometer 18.5, just downstream from the mouth of Poplar Creek. The section of river primarily affected by ORNL operations extends downstream from Clinch River kilometer 33.5, the entrance of White Oak Creek into Watts Bar Reservoir (Fig. 3.14).

Fig. 3.14. Map showing streams of the Oak Ridge area (with Clinch River miles 10 to 45 indicated). To convert miles to kilometers, multiply by 1.609.

Water quality

Water quality data are summarized in Tables 3.8 and 3.9. The data in Table 3.8 indicate that Clinch River water is moderately hard (hardness, 78 to 208 mg/liter as CaCO_3), alkaline (pH, 7.6 to 8.7), generally turbid (turbidity, 5 to 70 Jackson turbidity units; suspended solids, 6 to 42 mg/liter), and well oxygenated (dissolved oxygen, 6.1 to 11.2 mg/liter).

In general, all physical and chemical parameters measured for Clinch River water in the vicinity of the reservation comply with EPA and Tennessee State water quality criteria.^{36,37} Occasionally, however, levels of some parameters exceed the proposed criteria (Table 3.8). Nitrate concentrations (as N) at Clinch River kilometer 18.2 in 1973 ranged from 0.5 to 2.8 mg/liter (mean, 1.15 mg/liter).³⁸ A source of these high nitrate levels (values are high relative to upstream concentrations of less than 0.1 to 0.64 mg/liter) could be effluents and leachates from the Y-12 Plant via Bear and Poplar creeks. Ammonia and turbidity levels in the Clinch River (Clinch River kilometer 18 to 24) peaked in March at 0.9 mg/liter and 70 Jackson turbidity units respectively. Phosphate concentrations were also high during winter and early spring (less than 0.1 to 0.46 mg/liter) but dropped to acceptable levels during late spring through fall (less than 0.003 to 0.02 mg/liter).³⁸ These variations in nutrient and turbidity levels in the Clinch River are probably related to runoff from surrounding agricultural lands. Therefore, during periods of excessive runoff, these concentrations may temporarily exceed those recommended to prevent excessive eutrophication and water quality degradation in rivers and reservoirs (Table 3.8). The relatively high background concentrations of Al, Mn, and Fe in the Clinch River are probably a natural phenomenon due to the high content of Al, Mn, and Fe in the clay soils of the Oak Ridge area. Although maximum concentrations of 0.4 to 0.5 mg/liter of zinc were recorded during 1973,³⁸ mean levels of zinc for the Clinch River are generally less than 0.1 mg/liter, which is the maximum stream limit established as part of Tennessee State water quality guidelines.³⁷ Concentrations in the Clinch River of radionuclides of primary concern to radiological dose are listed in Table 3.10. The samples taken at location C-2 (Melton Hill Dam, 3.7 km above White Oak Creek) would be representative of ambient levels for the Oak Ridge vicinity because contaminants from White Oak Creek have not yet entered the channel. The percent of concentration guide for each isotope listed in Table 3.10 was less than 0.15%. The method for calculating percent of concentration guide for a known mixture of radionuclides is given in DOE Manual Chapter 0524.

Aquatic biota

Phytoplankton. A total of 132 phytoplankton taxa were collected during the Clinch River Breeder Reactor Program (CRBRP) monitoring effort;¹⁹ major genera were *Melosira* and *Oscillatoria*. Total numbers of phytoplankton cells per liter ranged from 406 in March to a maximum of 2170 in August.

Phytoplankton in the Clinch River probably originate from a number of different habitats, particularly from populations in low-flow areas and from benthic communities. River plankton populations are, in general, highly variable in time and in space.³⁹ However, the basic successional pattern observed from March through September 1974 (Fig. 3.15) is probably typical for Tennessee. Chrysophyta (mainly diatoms) dominate the phytoplankton during winter and decrease in both numbers of species and proportions of total individuals per species in summer.¹⁹ Cyanophyta (blue-green algae) can increase and become dominant during the summer, but this increase depends on rainfall and river-water levels. A summer increase in Chlorophyta (green algae) is also common. In early to midautumn, blue-green and green algae decrease, and the diatoms again become the dominant phytoplankton group. Collections of phytoplankton in the Clinch River are typical for large, relatively slow-moving rivers with extensive reservoir development.³⁹

Table 3.8. Summary of Clinch River water quality data (CRM 11-18) and water quality criteria (concentrations measured as milligrams per liter unless otherwise noted)

Parameter	Maximum	Minimum	Mean	For protection of aquatic life	For public water supplies	Tennessee receiving water maximum stream limit unless otherwise noted ^a	Percent criteria (mean value/minimum criteria)
Dissolved oxygen	11.2	6.1	8.1	5.0 (minimum)	3.0 (minimum)	5.0 (minimum) ^b	
pH	3.7	7.6	8.1	6.0-9.0 ^c	5.0-9.0 ^c	6.5-8.5	
Specific conductance (µmhos/cm)	245	130	207				
Total alkalinity (CaCO ₃)	106	76	92				
Hardness	208	78	126				
Turbidity (Jackson turbidity units)	70	5	16	50 ^d			32
BOD	3.0	<1	2.1			5.0	42
Chlorine residual	0.05	<0.05	<0.05	0.003 ^e		0.1	
Total dissolved solids	510	76	177		500	500	35
Suspended solids	42	6	18	80 ^c			23
Nitrite (as N)	0.065	<0.001	<0.014		1		<1.4
Nitrate (as N)	2.80	<0.1	0.56	0.5 ^c	10	10	113
Ammonia (as N)	0.90	0.09	0.34	0.02 ^c	0.5 ^c	1.5 (0.5)	1700
Total phosphate (as P)	0.46	<0.003	<0.13	0.05 ^c			<265
Ortho phosphate (as P)	0.10	<0.003	0.022				
Sulfate	165	4	37		250 ^c	250	15
Fluoride	2.6	<0.1	0.57	1.5 ^e	1.4-2.4 ^c	1.0	57
Al	3.32	<0.1	<0.8	0.1 ^{c,f}		1	<800
Cd	<0.005	<0.002	g	0.03-0.004 ^c	0.01 ^c	0.01	
Cr	1.94	<0.005	<0.45	0.05 ^c	0.05 ^c	0.05	<890
Cu	<0.013	<0.004	<0.007	~0.015 ^c	1	0.02	<48
Mn	0.079	0.02	0.06		0.05	1.0 (0.05)	110
Pb	<0.03	<0.01	g	~0.03 ^c	0.05	0.05	
Zn	0.5	<0.005	0.06	~0.1 ^c	5 ^e	0.1	60
Hg (ppb)	<4	<0.5	<1.4	0.05 ^c	2 ^e	5	
U	<0.01	<0.01	g				
Fe	0.68	0.08	<0.3		0.3	1.5 (0.3)	<100
Ni	<0.04	<0.01	g	~0.1 ^c		0.1	

^aDivision of Water Quality Control, Tennessee Department of Public Health, *Guidelines for Effluent Criteria for Sewage and Industrial Wastewater*, mimeo, January 1973.^bTennessee Water Quality Control Board, *General Water Quality Criteria for the Definition and Control of Pollution in the Waters of Tennessee*, mimeo, adopted on 26 Oct. 1971, Amended on 14 Dec. and 30 Oct. 1973.^cNational Academy of Sciences and National Academy of Engineering, *Water Quality Criteria - 1972*, Environmental Protection Agency, U.S. Government Printing Office, Washington, D.C., 1973.^dFederal Water Pollution Control Administration, *Water Quality Criteria*, U.S. Government Printing Office, Washington, D.C., April, 1958.^eJ. E. McGee and H. W. Wolf, eds., *Water Quality Criteria*, 2nd ed. The Resources Agency of California, State Water Resources Control Board Publ. No. 3-A, 1963.^fR. A. Freeman and W. H. Everhart, "Toxicity of Aluminum Hydroxide Complexes in Neutral and Basic Media to Rainbow Trout," *Trans. Amer. Fish. Soc.* 100: 644-658 (1971).^gAll measurements below levels of detection.

To convert from miles to kilometers, multiply by 1.609.

Table 3.9. Chemical water quality data in the Clinch River for 1977 and 1978

Substance	Standard ^a	Average concentration (mg/liter)					
		Sampling station C-2 ^b		Sampling station C-3 ^c		Sampling station C-4 ^d	
		1977	1978	1977	1978	1977	1978
Cadmium	0.01			<0.005	<0.005	<0.005	<0.005
Chromium	0.05	0.00003 ± 0.00005	<0.005	<0.01 ± 0.01	<0.006 ± 0.001	<0.01 ± 0.01	<0.006 ± 0.001
Cyanide	0.01			<0.001 ± 0.0004	<0.002 ± 0.0007	<0.002 ± 0.001	<0.002
Fluoride	1.0			<0.1	<0.1	<0.1	<0.2 ± 0.06
Lead	0.5			<0.01	<0.01	<0.01 ± 0.002	<0.01
Mercury	0.005	0.00002 ± 0.00003	<0.0005	<0.001	<0.001	<0.001	<0.001
Nickel	0.1			<0.008 ± 0.001	0.01 ± 0.004	<0.009 ± 0.004	0.01 ± 0.004
Nitrate	40	1.6 ± 4.0	<2.0 ± 2.8	2.4 ± 0.4	<2.4 ± 0.8	3.6 ± 2.0	3.2 ± 0.8
Sulfate	250			23 ± 4	25 ± 4.6	26 ± 6	26 ± 4
T.D.S.	500			158 ± 28	137 ± 25	176 ± 23	153 ± 14
Zinc	0.1	0.0002 ± 0.00005	<0.005	0.05 ± 0.02	0.08 ± 0.07	0.02 ± 0.008	0.1 ± 0.05

^aTennessee Stream Guidelines.^bLocated at Melton Hill Dam, 3.7 km above White Oak Creek.^cLocated at the ORGDP sanitary water intake, 10.1 km downstream from entry of White Oak Creek.^dLocated at the ORGDP recirculating water intake, downstream from Poplar Creek outfall, 14.8 km downstream from White Oak Creek.

Sources: *Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities, Calendar Year 1977, Y/UB-8*, Union Carbide Corporation, June 21, 1978; *Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities, Calendar Year 1978*, Union Carbide Corporation, June 1, 1979.

Table 3.10. Average concentrations of radioactive pollutants of primary concern in the Clinch River, 1977 and 1978

10⁻⁹ microcuries per milliliter

Radionuclide	Station C-2 ^a		Station C-3 ^b		Station C-5 ^c	
	1977	1978	1977	1978	1977	1978
⁹⁰ Sr	0.15 ± 0.08	0.09	0.18 ± 0.16	0.11 ± 0.05	0.27 ± 0.18	0.10 ± 0.06
¹³⁷ Cs	<0.01	0.24 ± 0.18	<0.03 ± 0.02	1.17 ± 1.47	0.5	0.71 ± 0.41
¹⁰⁶ Ru	0.10 ± 0.02	0.64 ± 0.60	0.15 ± 0.06	0.85 ± 0.87	0.19 ± 0.10	0.73 ± 0.73
³ H	490 ± 100	600 ± 400	1800 ± 850	2200 ± 1000	1000 ± 730	2200 ± 1300

^aLocated at Melton Hill Dam, 3.7 km above White Oak Creek.^bLocated at ORGDP sanitary water intake, 10.1 Km downstream from the entry of White Oak Creek.^cLocated at Centers Ferry near Kingston, Tennessee, 26.2 Km downstream from the entry of White Oak Creek.

Sources: *Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities, Calendar Year 1977, Y/UD-0*, Union Carbide Corporation, June 21, 1978; *Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities, Calendar Year 1978, Y/UB-10*, Union Carbide Corporation, June 1, 1979.

Zooplankton. A total of 56 zooplankton species were identified in sampling done from March to September 1974, of which 16 were arthropods and 40 were rotifers.¹⁹ Numbers of individuals collected per liter varied from 1.89 to 113.9; mean biomass estimates ranged from 22.3 to 297.4 g/liter, with the lowest zooplankton densities and lowest biomass recorded during the March sampling period.

Species composition and abundance of zooplankton in the Clinch River in the vicinity of ORNL are dependent primarily on recruitment of zooplankton from quiet areas such as creeks, main impoundment areas, and backwaters. Rotifers are almost always the dominant zooplankton in large rivers and are commonly represented by typically planktonic forms such as *Keratella*,

Fig. 3.15. Seasonal succession of phytoplankton in the Clinch River at kilometer 24.

Synchaeta, *Polyarthra*, *Asplanchna*, and *Brachionus*. Crustaceans are rarely numerous in the open-water areas of rivers, and those that are found usually belong to the genera *Cyclops* or *Bosmina*.³⁹

Macrophytes. The growth of macrophytes in the Clinch River below Melton Hill Dam (Clinch River kilometer 18 to 29) is generally sparse,³⁹ probably due to limited light penetration into the water, steep shorelines along much of this area, occurrence of hard substrate, and considerable fluctuations of the river water level. Occasional growths of the aquatic moss *Fontinalis* occur on submerged branches, and a leafy liverwort has been collected. Scattered patches of *Myriophyllum* occur in areas of suitable substrate and water depth. In Melton Hill Reservoir, however, macrophytes can obtain reasonably large standing crops; common taxa include *Potamogeton*, *Chara*, *Najas*, *Anacharis*, and *Myriophyllum* species. Fluctuating water levels and relatively high turbidities preclude the development of extensive stands, however.

Periphyton. Periphyton samples were collected in the Clinch River at kilometer 24 to 29 from March through October 1974 on Plexiglas slides exposed for two to four weeks. Of the 123 species and varieties collected, the greatest number (65 species and 4 varieties) belong to the division Chrysophyta, and most were diatoms.³⁹

The mean number of algal cells per square centimeter on the Plexiglas slides increased from a low of about 89,000 in March to a high of about 2,400,000 in August. The Chrysophyta (mostly diatoms) reached a high density early in the spring and maintained their abundance throughout the summer. Densities of Cyanophyta (blue-green algae), on the other hand, increased during summer and peaked in October. Generally, algae are opportunists; each species flourishes when and where conditions are optimal and then yields to other species as the environment changes.⁴⁰ Periphyton therefore occur as an irregular mosaic on stream and river beds and are subject to

great seasonal changes. Major controlling factors include substrate, temperature, light, and current.³⁹

Benthic macroinvertebrates. Macroinvertebrates collected from March to September 1974 included mollusks, annelids, insects, and coelenterates.¹⁹ Insects comprised the greatest number of species. Asiatic clams and oligochaetes (earthworm-like) were abundant throughout the sampling period. *Nais* was dominant in March and June, *Limnodrilus* in June through September, and coelenterate polyps (*Hydra*) in early June and August. Although Chironomidae were numerous in all samples, *Polypedilum*, *Cricotopus*, and *Dicrotendipes* were the only abundant genera. Ten members of the family Chironomidae, listed by the EPA⁴¹ as intolerant to decomposable organic wastes, were collected in the Clinch River benthic dredge samples; eight genera were collected on artificial substrates. Therefore the survey area (Clinch River kilometer 24 to 29) is apparently not heavily contaminated with decomposable organic wastes, according to this index.

In terms of biomass, the Asiatic clam was the dominant benthic macroinvertebrate in the study area (Clinch River kilometer 18 to 29).¹⁹ The Asiatic clam was introduced into this country prior to 1938, and by 1963 it had spread throughout the Tennessee River and lower Cumberland basins.⁴² In Tennessee, these small bivalves feed on phytoplankton and do not appear to be substrate-selective. From an economic viewpoint, the clam is generally a liability; the larvae can be drawn into water intakes and cause fouling. Very little is known about the use of this clam as a food item by other organisms. Analysis of stomach contents of fish collected at Clinch River kilometer 24 to 29 indicates that these clams may be a common food for carp and smallmouth buffalo.

Fish. Numerically dominant species collected in 1974 and 1975 at Clinch River kilometer 24 to 29 (by electroshocking) included threadfin shad, gizzard shad, skipjack herring, golden redhorse, carp, bluegill, sauger, and white bass.¹⁹ Additional important species collected included largemouth bass and shiners. Nongame species (i.e., forage and rough species) accounted for 87.6% of the total number of fish collected at Clinch River kilometer 24 to 29. In terms of biomass, rough fish comprised 70% of the fish collected, and forage fish comprised 18%; sauger and white bass were the dominant game fish.

In addition to sampling adult populations of fish, ichthyoplankton (fish eggs and larvae) were collected by stationary netting at Clinch River kilometer 24 to 29 from March 28 through August 29, 1974.¹⁹ Significant numbers of eggs were collected only on May 16 and June 2, which denote the onset of spring spawning for the species represented. Samples taken on all other dates yielded few, if any, eggs. However, a second spawning peak (although of lesser magnitude than the spring peak) is probable in early fall.

Quantitative data on the fisheries in the Clinch River in the vicinity of the Oak Ridge reservation are not available. The two most important species caught commercially in the Clinch River are smallmouth buffalo and channel catfish. Other species, such as bigmouth buffalo, black buffalo, black redhorse, golden redhorse, shorthead redhorse, blue catfish, and flathead catfish, are also taken but in lesser quantities. Carp are taken by some fishermen whenever a market can be established. The biomass of fish caught commercially is negligible compared with that obtained by sport fishing.¹⁹

A large number of sport fishermen use the Clinch River and its tributaries in the Oak Ridge vicinity every year. The spring migrations (February through June) of walleye, white bass,

white crappie, black crappie, and sauger stimulate a peak in angling activity. During the hot summer months (June through August), panfish (bluegill in particular) are the most common fish caught.

Summary

Figure 3.16 indicates the dominant species and major pathways of the food web projected for the aquatic community in the Clinch River. A turbid, moderately hard water system, the physical and chemical water-quality characteristics of the Clinch River are typical of many large rivers in the southeastern United States. Aquatic biota are relatively diverse and productive.

Endangered species

None of the fish species collected in either the CRBRP baseline environmental survey or the ORNL sampling programs are designated as endangered under the Endangered Species Act of 1973.⁴³

3.6.2.2 White Oak Creek, White Oak Lake, and Melton Branch

The White Oak Creek basin has an area of 16.5 km².²⁰ The headwaters occur on the forested slopes of Chestnut Ridge, north of ORNL (Fig. 3.14); numerous springs intersecting with the upper reaches of White Oak Creek combine to yield a relatively stenothermic aquatic environment. Stream width varies from 0.6 to 1.2 m, and depth varies from 10 to 25 cm. The stream-bed substrate is predominantly rocks (5 to 8 cm in diameter), with some exposed bedrock.

The base flow of White Oak Creek is low, and at times in late fall, periods of no natural flow have occurred. The belt of Knox dolomite underlying Chestnut Ridge, which forms the northwestern drainage divide of the basin, is the principal water-bearing formation. Several springs along the base and in the ridge valleys are tributaries to White Oak Creek. Ninety percent of dry-weather discharge originates as groundwater discharge from the Knox dolomite of Chestnut Ridge, from the Chickamauga limestone of Bethel Valley, and from effluents at ORNL.²⁰

The Melton Branch tributary of White Oak Creek drains 3.83 km² in Melton Valley and enters the creek 2.5 km above its junction with the Clinch River.

Liquid wastes from ORNL facilities that are discharged to Melton Branch or White Oak Creek consist of cooling-tower blowdown that contains chromates and phenols, effluents from a primary sewage treatment facility, waste from ion-exchange resin regeneration, and effluent from the treatment of low-level radioactive wastes. Nonradioactive chemical wastes from ORNL operations, including a large number of discharges collected from research laboratory drains, are discharged into White Oak Creek without substantial treatment.

In addition to receiving routine discharges of various effluents, both Melton Branch and White Oak Creek receive drainage and leachates from ORNL waste disposal areas (Fig. 3.17).

At a point about 1.6 km above the confluence with the Clinch River, White Oak Creek enters White Oak Lake, an 8-ha reservoir constructed in 1943 for impounding liquid wastes from ORNL. The waters of White Oak Lake discharge over the dam at a rate of 0.4 m³/sec about 80% of the time.²⁰

Fig. 3.16. Aquatic food web in the Clinch River in the vicinity of ORNL.

Fig. 3.17. Location of White Oak Creek, White Oak Lake, and Melton Branch in relation to ORNL facilities.

Water quality

Water analyses from five stations on White Oak Creek and Melton Branch are summarized for 1970 and 1971 in Tables 3.11 and 3.12. Water quality data measured in 1977 and 1978 at White Oak Dam are presented in Table 3.13.

Table 3.11. Average concentrations (in mg/liter) of nonradioactive pollutants for White Oak Creek in 1970

Contaminant	EPA standard	Sampling station ^a				
		W-1 Flume	W-2 Settling basin	W-3 Whiteoak Creek (ORNL)	W-4 Melton Branch	W-5 Whiteoak Dam
Cl ⁻	250	14	34	21	41	11
F ⁻	1.7	1.1	1.6	0.8	1.2	0.9
NO ₃ ⁻	10	1.7	23.3	1.1	2.2	1.3
Phenols	0.001	0.0017	0.0013	0.0015	0.0011	0.0004
SO ₄ ²⁻	250	34	22	31	71	29
TDS ^b	500	152	202	121	371	99
COD ^c						7.5
Ag	0.05	<0.002	<0.002	<0.002	<0.002	<0.008
As	0.01	<0.02	<0.02	<0.02	<0.02	<0.02
Ba	1.0	0.036	0.03	0.026	0.083	0.053
Be	1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cd	0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Cr ⁺⁶	0.05	0.124	0.047	0.076	0.538	0.10
Cu	1.0	0.049	0.120	0.088	0.026	<0.032
Fe	0.3	0.04	0.10	0.09	0.02	0.17
Mn	0.05	<0.007	<0.02	<0.007	<0.008	<0.01
Se	0.01					
Zn	5	<0.05	<0.05	<0.05	<0.03	<0.05
Alkaline metals		65.6	142	57.0	41.3	83.5
(pH)	6-9	8.3	8.7	8.2	8.2	8.0)

^aSee Fig. 3.17 for locations of sampling stations.

^bTDS = total dissolved solids.

^cCOD = chemical oxygen demand.

Table 3.12. Average concentrations (in mg/liter) of nonradioactive pollutants for White Oak Creek in 1971

Contaminant	EPA standard	Sampling station ^a				
		W-1 Flume	W-2 Settling basin	W-3 Whiteoak Creek (ORNL)	W-4 Melton Branch	W-5 Whiteoak Dam
Cl ⁻	250	2	6	5	6	4
F ⁻	1.7	0.3		1.1	1.2	1.0
NO ₃ ⁻	10	51.8	20.5	10.3	7.2	5.3
Phenols	0.001	0.0001	0.0003	0.0002	0.0003	0.0005
SO ₄ ²⁻	250	29	33	28	49	34
TDS	500	199	357	157	245	159
COD						1.1
Ag	0.05	<0.011	0.015	<0.008	<0.008	<0.006
As	0.01	<0.053	<0.053	<0.053	<0.053	<0.053
Ba	1.0	0.036	<0.016	0.033	0.036	0.050
Be		<0.001	<0.0013	<0.001	<0.001	<0.0007
Cd	0.03	<0.03	<0.030	<0.030	<0.030	<0.030
Cr	0.05	0.53	0.33	0.33	0.56	0.43
Cu	1.0	0.02	1.046	0.012	0.013	0.006
Fe	0.3	0.10	0.16	0.05	0.07	0.04
Hg	0.0002	<0.0027	<0.005	<0.0022	<0.0016	<0.0019
Mn	0.05	<0.01	0.026	<0.01	<0.01	<0.01
Pb	0.05	0.02	0.060	0.015	<0.016	<0.016
Se	0.01					
Zn	5.0	<0.07	<0.13	<0.07	0.10	<0.10
Alkaline metals		74.9		73.6	66.2	83.7
(pH)	6-9	7.7		7.6	7.9	7.9)

^aSee Fig. 3.17 for locations of sampling stations.

Table 3.13. Chemical water quality data at White Oak Dam for 1977 and 1978

Substance	Standard concentration ^a (mg/liter)	1977		1978	
		Average concentration (mg/liter)	Percent of standard	Average concentration (mg/liter)	Percent of standard
Chromium	0.05	0.003 ± 0.002	6	<0.008 ± 0.006	<16
Mercury	0.005	0.0003 ± 0.0005	6	<0.0005	<10
Nitrate	40	3.2 ± 2.4	8	6.4 ± 8.8	16
Zinc	0.1	0.005 ± 0.02	5	<0.005 ± 0.002	<5

^aTennessee Stream Guidelines.

Sources: *Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities, Calendar Year 1977*, Y/UB-8, Union Carbide Corporation, June 21, 1978; *Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities, Calendar Year 1978*, Y/UB-10, Union Carbide Corporation, June 1, 1979.

Upstream from ORNL, White Oak Creek is a small clear, hardwater stream of good water quality. Phosphate, nitrate, and heavy-metal concentrations are generally low. Laboratory discharges, leachates, and drainage from waste disposal areas combine to render the stream significantly poorer in quality in the lower reaches of the waterway.

Concentrations of ⁹⁰Sr, ¹³⁷Cs, ¹⁰⁶Ru, and ³H at the confluence of White Oak Creek and the Clinch River are presented in Table 3.14 for 1976 and 1977. These are calculated values based on the concentrations measured at White Oak Dam and the dilution afforded by the Clinch River. The yearly average dilution for 1976 was 422 and that for 1977 was 537. The percent of concentration guide for each isotope listed in Table 3.14 was 0.51% in 1976 and 0.28% in 1977. The method for calculating percent of concentration guide for a known mixture of radionuclides is given in DOE Manual Chapter 0524. Radioactive materials (e.g., fallout) that may enter the Clinch River upstream of the White Oak Creek outfall are not included in this calculation (see Table 3.10, station C-2).

Aquatic biota

Flora. The creek system as a whole is comprised of two distinct habitat types: (1) fast-flowing waters of the stream proper and (2) relatively static impounded areas.

Table 3.14. Radionuclide concentrations in the Clinch River contributed by White Oak Creek in 1976 and 1977

Radionuclide	Concentration of radionuclides of primary concern (10 ⁻⁹ μCi/ml)					
	1976			1977		
	Maximum	Minimum	Average	Maximum	Minimum	Average
⁹⁰ Sr	2.6	0.17	1.28 ± 0.23	1.85	0.26	0.62 ± 0.24
¹³⁷ Cs	0.20	0.01	0.07 ± 0.02	0.26	0.01	0.05 ± 0.04
¹⁰⁶ Ru	0.08	0.01	0.04 ± 0.01	0.15	0.01	0.05 ± 0.02
³ H	4000	320	2000 ± 317	4400	280	1450 ± 680

Sources: Energy Research and Development Administration, *Environmental Monitoring Report, United States Energy Research and Development Administration, Oak Ridge Facilities, Calendar Year 1976*, Y/UB-6, Union Carbide Corporation, May 1, 1977; *Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities, Calendar Year 1977*, Y/UB-8, Union Carbide Corporation, June 21, 1978.

The phytoplankton of White Oak Lake were studied in a qualitative manner by Krumholz⁴⁴ from 1950 to 1953 and by Andrews^{45,46} in 1973. Seventy-nine genera were recorded, the majority of which belong to the Chlorophyta.

Quantitative data for White Oak Lake phytoplankton are limited. In collections available, dominant genera were *Pleodorina*, *Closterium*, and *Euglena*. For samples taken July 25, 1973, three neustonic species of *Euglena* were dominant. Macroscopic filamentous mats were principally *Spirogyra* sp., *Oedogonium* sp., and *Hydrodictyon reticulatum*.

From 1950 to 1953 Krumholz⁴⁴ sampled (qualitatively) attached algae from White Oak Lake and periphyton and phytoplankton in White Oak Creek above and below ORNL.

The macrophytes of White Oak Creek and White Oak Lake have not been studied.

Fauna. Qualitative samplings of zooplankton in White Oak Lake were taken from 1950 to 1953.⁴⁴ Rotifers were the most common organisms collected; densities were highest during the summer.

Zooplankton in White Oak Creek have not been extensively studied. Populations in the creek would likely be less dense and less diverse than those found in the lake.

Benthic macroinvertebrates were collected (qualitatively) by Krumholz⁴⁴ from White Oak Lake and White Oak Creek above and below the ORNL settling basin, Melton Branch, Lagoon Creek, and a small spring-fed stream on the south side of White Oak Lake. Surber samples taken in White Oak Creek above ORNL indicate a diverse fauna. The mayfly *Baetis*, an insect common in small rocky streams, was the predominant species. The snail *Goniobasis clavaeformis* and the isopod *Lirceus* were also common in collections. Freshwater isopods are primarily inhabitants of unpolluted shallow waters.

Krumholz⁴⁴ collected 23 species of fish from White Oak Creek at unspecified locations. Fish were sampled from the mouth of the creek to 200 m upstream; from July 1974 to February 1975, a total of 11 species (607 individual fish) were collected. Gizzard shad, threadfin shad, and carp were predominant.

3.7 SOCIOECONOMIC PROFILE

3.7.1 Area population

Oak Ridge National Laboratory is part of the DOE reservation, located in Anderson and Roane counties. Five counties surround the site: Anderson, Knox, Loudon, Roane, and Morgan. The combined population of the five counties in 1970 was 413,359; most of the population (336,593) was located to the east of the site in Anderson and Knox counties. The 1975 estimated population for the five counties was approximately 437,600, a 6% increase since 1970.

There are two major population centers within 75 km of the site: Oak Ridge, located in both Roane and Anderson counties, with the nearest residential section being 8 km north; and Knoxville, located in Knox County, being approximately 35 km east. Figure 3.18 shows all communities with a population above 1500 within 100 km of the DOE reservation. Table 3.15 lists the 1960 and 1970 population figures and projections for 1980 and 1990 for all the counties containing communities within a 75-km radius of the site. Also included are the rural and urban populations for each county in 1960 and 1970.

Fig. 3.18. Communities with a population greater than 1500 within 100 km of the DOE reservation.

3.7.1.1 Anderson County

In 1970 Anderson County had a population of 60,300 residents, 54% of whom were urban. The 1975 population estimate of Anderson County's population was 61,200, a 1.5% increase over the 1970 figures. Oak Ridge, Anderson County's largest city, had a 1970 population of 26,829, a figure estimated to be essentially unchanged as of 1975.

Anderson County has two fairly distinct population groups. This distinction exists because of the unique way in which the city of Oak Ridge was formed. In the 1940s, the Federal government acquired approximately 23,600 ha in Anderson and Roane counties for a reservation to be used for weapons development during World War II. One small part of this parcel of land was set aside for residential and support-service use by employees of the government. The remainder of the land was used for industrial and research purposes. In 1959, the community part of the reservation, Oak Ridge, became self-supporting and self-governing. At that time, the entire "Oak

Table 3.15. 1960, 1970, and projected population for counties containing communities within 80 km of the ORNL site

County and subdivisions	1960 ^a	1970 ^a	1980 ^b	1990 ^b
Impacted counties				
Anderson County	60,032	60,300	64,909	74,988
Urban	32,067	33,831		
Rural	27,965	26,469		
Clinton	4,943	4,794		
Lake City	1,914	1,923		
Norris	1,389	1,359		
Oak Ridge ^c	27,124	26,829		
Oliver Springs ^c	336	2,208		
Knox County	250,523	276,293	313,126	353,364
Urban	172,734	190,502		
Rural	77,789	85,791		
Knoxville	111,827	174,587		
Loudon County	23,757	24,266	26,685	30,359
Urban	8,791	9,052		
Rural	14,966	15,214		
Greenback	285	318		
Lenoir City	4,979	5,324		
Loudon	3,812	3,728		
Philadelphia		554		
Morgan County	14,304	13,619	13,860	15,082
Urban		34		
Rural	14,304	13,585		
Oliver Springs ^c		34		
Oakdale	470	376		
Wartburg		541		
Roane County	39,133	38,881	40,741	44,728
Urban	14,205	20,788		
Rural	24,928	18,093		
Harriman	5,931	8,734		
Kingston	2,010	4,142		
Oak Ridge ^c	45	1,490		
Oliver Springs ^c	827	1,163		
Rockwood	5,345	5,259		
Other counties and communities				
Blount County	57,525	63,744	74,524	85,293
Urban	21,811	26,892		
Rural	35,714	36,852		
Alcoa	6,396	7,739		
Eagleton Village	5,068	5,345		
Friendsville	606	575		
Maryville	10,348	13,808		
Townsend	283	267		
Campbell County	27,936	26,045	26,394	27,806
Urban	6,204	6,902		
Rural	21,732	19,143		
Caryville		648		
Jellico	2,210	2,235		
Jacksboro		689		
La Follette	6,204	6,902		
Cumberland County	19,135	20,733	23,232	26,308
Urban	4,668	5,381		
Rural	14,467	15,352		
Crossville	4,668	5,381		
Pleasant Hill	267	293		

Table 3.15 (continued)

County and subdivisions	1960 ^a	1970 ^a	1980 ^b	1990 ^b
Fentress County	13,288	12,593	13,616	14,944
Urban				
Rural	13,288	12,593		
Allardt		610		
Jamestown	1,727	1,899		
McMinn County	33,662	35,462	38,803	43,325
Urban	15,326	15,526		
Rural	18,336	19,936		
Athens	12,103	11,790		
Calhoun		624		
Englewood	1,574	1,878		
Etowah	3,223	3,736		
Niota	679	629		
Meigs County	5,160	5,219	6,017	6,752
Urban				
Rural	5,160	5,219		
Dccatur	681	698		
Monroe County	23,316	23,475	25,445	28,256
Urban	4,145	6,954		
Rural	19,171	16,521		
Madisonville	1,812	2,614		
Sweetwater	4,145	4,340		
Tellico Plains	794	773		
Vonore		524		
Rhea County	15,863	17,202	19,100	20,706
Urban	3,500	4,361		
Rural	12,363	12,841		
Dayton	3,500	4,361		
Graysville	838	951		
Spring City	1,800	1,756		
Scott County	15,413	14,762	15,039	17,518
Urban		2,602		
Rural	15,413	12,160		
Huntsville		337		
Oneida	2,480	2,602		
Sevier County	24,251	28,241	34,004	39,533
Urban	2,890	2,661		
Rural	21,361	25,580		
Gatlinburg	1,764	2,329		
Pigeon Forge		1,361		
Sevierville	2,890	2,881		
Union County	8,498	9,072	10,081	10,644
Urban				
Rural	8,498	9,072		
Luttrell		819		
Maynardville	620	702		

^aU.S. Bureau of the Census, *U.S. Census of Population: 1970 Number of Inhabitants*, Final Report PC(1)-A44, Tennessee.

^bThe Tennessee State Planning Office, *Tennessee Migration, Population, Families, Income, and Manpower Demand Projections to 1990 for Development Districts and Counties*, 1974.

^cIn more than one county.

Ridge reservation" was designated as the city of Oak Ridge, although approximately 15,000 ha remained in the custody of AEC.

Anderson County residents, exclusive of Oak Ridge, share many common traits and characteristics with the surrounding rural Tennessee population. Oak Ridge, on the other hand, has demographic characteristics that set the community apart from other communities in the area and from the rural population. For example, in 1970 Anderson County had a rural black population of 228 (less than 1%), which is similar to the rural population of the region. Although only 5.5% of Oak Ridge citizens are black, Oak Ridge contains over 75% of all blacks in Anderson County. Additional differences between the two groups are that the Anderson County residents outside Oak Ridge are more normally distributed by age groups, whereas Oak Ridge has proportionally more working-aged and proportionally fewer retirement-aged people; only 52.8% of Oak Ridge's citizens are native Tennesseans, compared with 85.9% native Tennesseans in the remainder of Anderson County; virtually all foreign-born residents in Anderson County live in Oak Ridge.

The creation of Oak Ridge was the main contributing factor in the urbanization of the previously rural area. Population growth in Anderson County was most dramatic between 1940 and 1950 as a consequence of the establishment of the Federal reservation. Between 1950 and 1970 the population increased by only a small amount, from 59,407 to 60,300.

3.7.1.2 Knox County

Knox County has by far the largest population of any county in the area. Knox County grew steadily in the 1960s from 250,523 in 1960 to 276,293 in 1970, a 10% increase. This growth has continued into the 1970s, with a population estimated at 310,000 as of November 1, 1976, an average annual increase of 4935 persons. If this growth rate continues, Knox County's population will exceed by a substantial amount the 1980 estimate of 313,126 as proposed by the Tennessee State Planning Office. West Knox County is currently the main growth area of Knoxville. This growth is due to a variety of factors. Interstate 40 has provided residents easy access to either Knoxville or Oak Ridge for employment opportunities. Additionally, the availability of suitable land has encouraged substantial residential and commercial development.

3.7.1.3 Roane County

The population of Roane County grew steadily from 1940 to 1960 but declined slightly by 1970. According to the 1970 census, Roane County had 38,881 residents. Recent 1975 population estimates suggest a 1975 population of approximately 40,600 residents, a 4.5% increase since 1970. Like Knox County, if Roane County's growth pattern continues, the population will exceed the 1980 estimate proposed by the Tennessee State Planning Office.

The county is undergoing a change from rural to urban, with slightly over half of the population (53.5%) in the 1970 census classified as urban residents. The urban areas are Kingston (4142), Harriman (8734), Rockwood (5259), and parts of Oliver Springs and Oak Ridge, which comprise the balance of urban areas within the county.

3.7.1.4 Loudon County

Loudon County is a small predominantly rural county; it contains two small cities, Lenoir City and Loudon. Loudon County had a fairly uniform growth rate from 1950 to 1970, with 23,182 in 1950, 23,757 in 1960, and 24,266 in 1970. A recent population estimate suggests a 1975 popula-

tion of 26,300 residents, an 8.6% increase since 1970. The growth of both urban and rural areas of the county has been about the same, with both categories showing approximately the same growth from 1960 to 1970. However, the urban areas of the county, Lenoir City and Loudon, have not grown equally. The city of Loudon lost population from 1960 to 1970, while Lenoir City gained (Table 3.15). Lenoir City is closer to the ORNL site, being on the route from Oak Ridge to Loudon (Fig. 3.18).

3.7.1.5 Morgan County

Of the five counties surrounding the reservation, Morgan County is the largest in land area but the smallest in population. The 1970 census records a population of 13,619 residents; a recent state estimate shows a 1975 population of approximately 14,400, a 5.9% increase since 1970. This 1975 estimate already exceeds the 1980 population estimate of 13,860 as proposed by the Tennessee State Planning Office.

Except for a small part of Oliver Springs (34 people), all of Morgan County is classified as rural (Table 3.15). The largest community is Wartburg, with a population of 571.

The five-county impact area is growing at a rate that is faster than that proposed by the Tennessee State Planning Office. If the 1970-1975 growth trend continues, four of the five designated communities will have 1980 populations that exceed the estimated populations as proposed. Currently, the Knox County standard metropolitan statistical area (SMSA) is the fastest growing SMSA in the state.

3.7.2 Current DOE profile in communities

The development and operation of the DOE installations (previously the Manhattan Project, U.S. AEC, and ERDA) have greatly influenced the region. The plants have recruited numerous workers from outside the region, created long-term permanent employment for many local citizens, contributed to the development and growth of towns and cities, and affected the operation of a variety of social and political institutions. The following discussion describes the current profiles of many of these influences.

3.7.2.1 Current DOE and DOE-contractor employment profile

Employment in the atomic energy program at Oak Ridge is divided among DOE (prior to February 1975, the Atomic Energy Commission; from February 1975 to October 1977, ERDA) and its principal operating contractors: Union Carbide Corporation, Nuclear Division (UCC-ND), which operates the Oak Ridge Gaseous Diffusion Plant (ORGDP), the Oak Ridge Y-12 Plant, and the Oak Ridge National Laboratory (ORNL); Oak Ridge Associated Universities (ORAU); and the University of Tennessee, which operates the Comparative Animal Research Laboratory (CARL). In 1976, these installations employed an average of 17,400 persons distributed among the installations as shown in Table 3.16.

Overall, the three major installations operated by UCC-ND under contract with DOE have provided a rather stable source of employment for 30 years, averaging about 13,000 employees annually (Table 3.17). These figures do not include the people employed to construct the plants; at the peak construction period in mid-1945, an estimated 70,000 workers were involved in the construction of the three plants. Since 1973 total employment at the three plants has grown substantially (by about 4000 workers); however, of the three plants only ORNL and ORGDP have actually expanded.

Table 3.16. Employee distribution among ERDA contractor installations, 1976

Installation	Number employed	Percent
ORGDP	6,000	35
ORNL	5,200	30
Y-12	4,800	28
CARL	102	<1
ORAU	355	2
ERDA	927	5
Total	17,384	

Table 3.17. Employment levels at ORGDP, ORNL, and Y-12 — 1943 to 1976^a

Facility	1943	1947	1952	1955	1958	1960	1963	1966	1969	1973	1974	1975	1976
ORGDP	4,900	4,900	4,900	4,280	4,952	4,150	2,700	2,570	2,750	3,000	4,300	5,000	6,000
ORNL	3,000	3,000	3,000	3,120	3,735	4,200	4,480	5,190	5,100	4,100	4,500	5,000	5,200
Y-12	3,560	3,560	3,560	3,560	6,225	5,203	5,420	4,440	5,400	6,000	5,400	5,000	4,800
Total	11,460	11,460	11,460	10,960	14,912	13,553	12,600	12,200	13,250	13,100	14,200	15,000	16,000

^aYearly averages.Source: C. R. Meyers, Jr., *Spatial Distribution and Employment Trends of Manufacturing Industries in East Tennessee, 1943-1973*, ORNL/NSF/EP-38, Oak Ridge National Laboratory, Oak Ridge, Tenn., June 1974, pp. 16-17.

3.7.2.2 Employee residence

In recent years, less than half of the work force resided in Oak Ridge; for example, in 1975, 34.6% lived in Oak Ridge, 21.4% lived in Knoxville, and the remaining 44% lived in the surrounding counties or in smaller outlying towns and communities (Table 3.18).

The impact of geographical distance and access on residence location of employees is not easily discernible from data available (Table 3.19). With respect to ORGDP personnel, there is a slightly higher probability for them to live in Kingston or Harriman than for employees of the other two plants; however, fewer Y-12 employees live in Oak Ridge than do employees of ORNL and ORGDP, a situation suggesting that occupational classification is probably a better indicator of residence location than geographical distance to the plant.

3.8 LAND USE

The Oak Ridge reservation consists of approximately 15,000 ha. Three separate industrial sites (Y-12 Plant, Oak Ridge Gaseous Diffusion Plant, Oak Ridge National Laboratory), an agricultural research complex (Comparative Animal Research Laboratory), ecological research areas, and managed forests provide for intensive use of the reservation. Within 16 km of the HFEL facilities are three incorporated towns (Oak Ridge, Oliver Springs, and Lenoir City) with a combined population of 37,000.¹⁹ Major highways include Interstate 40, about 1.5 km south of the reservation, and Interstate 75, about 3.2 km southeast of the reservation. State Highways 95, 58, and 62 pass through or adjacent to the reservation. The Tennessee Valley Authority Melton Hill and Watts Bar reservoirs form most of the southern and western boundaries of the reservation and attract both fishermen and boaters. Only one airport (the Oak Ridge Air Park, a general aviation facility) is within 16 km of the facilities. No commercial air routes pass over the reservation.¹⁹ A formal land use plan⁴⁷ for the reservation was formulated in 1975.

Table 3.18. Payroll and residence information Oak Ridge area
(ERDA and CPFF contractors), December 1975^a

Residence	Number of employees ^b	Percent of employees	Payroll ^b	Percent of payroll
Total (includes all CPFF contractor employees except construction) ^c	16,007	100.0	\$232,850,134	100.0
<u>Place of residence</u>				
City of Oak Ridge	5,536	34.6	90,846,524	39.0
Anderson, outside Oak Ridge	2,115	13.2	27,602,358	11.9
Roane, outside Oak Ridge	2,054	12.8	26,320,368	11.3
Other locations	6,302	39.4	88,080,886	37.8
<u>Countries</u>				
Roane and Anderson	9,705	60.6	144,769,248	62.2
Knox	4,357	27.2	63,617,021	27.3
Loudon	888	5.4	11,104,685	4.8
Morgan	269	1.7	3,100,276	1.4
Blount	235	1.5	3,013,727	1.3
Campbell	170	1.1	2,089,220	0.9
Monroe	125	0.8	1,430,678	0.6
McMinn	51	0.3	650,874	0.3
Other	227	1.4	2,934,405	1.2
<u>Selected cities^d</u>				
Knoxville	3,424	21.4	49,331,269	21.2
Clinton	1,198	7.5	16,016,854	6.9
Kingston	965	6.2	13,217,354	5.7
Lenoir City	700	4.4	9,194,683	3.9
Harriman	638	4.0	7,721,505	3.3
Oliver Springs	592	3.7	6,846,767	2.9
Rockwood	252	1.6	3,076,001	1.3

^aThe Atomic Energy Commission (AEC) was succeeded by the Energy Research and Development Administration (ERDA) on January 19, 1975. CPFF—Cost plus fixed fee.

^bEmployees on the payrolls for pay period ending December 31, 1975, or nearest to that date. Payroll data include actual annual salaries and wages paid to such employees in calendar year 1975 except in cases of new hires for which an annualized December monthly salary or wage is reported.

^cIncludes ERDA—Oak Ridge Operations and Headquarters Extensions in Oak Ridge, UCC-ND, ORAU, UT-CARL, and Rust (nonmanual and manual maintenance employees).

^dEmployees live in these cities or on rural postal routes served from these cities.

3.9 WATER USE

Major water uses in the vicinity of ORNL include water withdrawals for industrial and public water supplies, commercial and recreational water traffic, and other recreational activities such as swimming and fishing.

Major water withdrawals from the Clinch River are 21,000 m³/day at Clinch River kilometer 18.5 and 9,500 m³/day at Clinch River kilometer 23.2 for DOE Oak Ridge Operations, 83,000 m³/day at Clinch River kilometer 66.8 for the City of Oak Ridge and DOE (ORNL obtains its water from this source), 2.16 x 10⁶ m³/day at Clinch River kilometer 76.6 for the TVA Bull Run Steam Plant, and 4,000 m³/day at Clinch River kilometer 75.5 for the West Knox Utility District.

Groundwater use (wells) within 32 km includes not only industrial (1,300 m³/day) and public water supplies (1,100 m³/day) but also a large number of small-capacity individual and multiunit

Table 3.19. Residence location for UCC-ND employees 1974

	ORGDP		Y-12		ORNL	
	Number	Percent	Number	Percent	Number	Percent
Urban						
Oak Ridge	1,339	33.7	1,592	29.2	2,024	42.7
Clinton	284	7.2	514	9.4	221	4.7
Oliver Springs	177	4.5	229	4.2	98	2.1
Harriman	227	5.7	249	4.6	88	1.9
Kingston	377	9.5	275	5.0	233	4.9
Knoxville	671	16.9	1,221	22.4	1,113	23.5
Lenoir City	185	4.7	225	4.1	224	4.7
Rural						
Within 20 miles	267	6.7	457	8.4	360	7.6
20 to 30 miles	233	5.9	355	6.5	183	3.9
30 to 40 miles	118	3.0	193	3.5	111	2.3
40 to 50 miles	35	0.9	74	1.4	21	0.4
Over 50 miles	58	1.5	75	1.4	66	1.4
Total outside						
Oak Ridge	2,632	66.3	3,867	70.8	2,718	57.3

Source: Union Carbide Corp., *Industrial Relations Report*, Nuclear Division, Oak Ridge, Tenn., 1975.

domestic wells. ORNL uses between 500 and 1,000 m³/day of local-well groundwater (depending on time of year) in its fish-research laboratories.

The Clinch River is the major groundwater sink for the area. Discharge from the aquifer system at ORNL flows directly into the river or its tributaries (Melton Branch and White Oak Creek). Because the incised meander of the Clinch River is a major topographic feature set in bedrock,⁴⁸ it is unlikely that a significant groundwater flow passes beneath the river. No groundwater wells are located where they could potentially intercept seepages from the plant site before discharge into the Clinch River system.

The Clinch River (Melton Hill Reservoir) adjacent to the ORNL property is a component of the Inland Waterway System, which allows commercial navigation to the Gulf of Mexico. Commercial traffic locked through Melton Dam amounted to 2720 metric tons in 1975. In 1974, 631 recreational craft passed through Melton Hill locks.

Recreational use of the lands and waters in the Oak Ridge region is heavy (Sect. 3.8). Although no quantification of recreational use such as swimming, fishing, and localized recreational boating is available, a large proportion of these recreational areas are located along waterways, and frequent recreational interactions with water are assumed.

3.10 REGIONAL LANDMARKS

3.10.1 Historic

Among the early settlers in what is now the Oak Ridge reservation were William Tunnell, Anne Howard, Isaac Freels, and Collins Roberts. The descendants of these families were still in the area when the Corps of Engineers acquired the land for the Manhattan Project in 1942. Many current place names on the reservation, such as Freels Bend and Robertsville, were derived from these early settler families.⁴⁹

A grist mill existed on the East Fork of Poplar Creek before 1796, when Tennessee was still a part of North Carolina. Walker's Mill was built where the East Fork empties into Poplar Creek, near the present site of the Oak Ridge Gaseous Diffusion Plant.⁵⁰

Sparsely written history of the area indicates that a Methodist church existed in the early days of settlement. Mount Zion Baptist Church was founded in the early 1850s, and Cumberland Presbyterian Church followed along with George Jones Memorial Baptist Church (the only structure left in the group).⁵⁰

Also located in the area at the time of the 1942 acquisition by the U.S. Government were the East Fork Masonic Lodge, Robertsville School, Wheat High School, Adam's Store and Post Office, and many clapboard houses and log cabins. A ferry existed at the present Gallaher Bridge site until the late 1930s.

A research team from the Department of Anthropology, University of Tennessee, Knoxville, conducted an archaeological survey⁵¹ of the proposed gas centrifuge plant site at the western end of the Oak Ridge reservation adjacent to Oak Ridge Gaseous Diffusion Plant. The purpose of the survey was to locate, inventory, and evaluate the prehistoric and historic cultural resources in the proposed impact area. One conclusion⁵¹ was that there are no historic structures or sites that require preservation or mitigation of adverse impact under the criteria of the *National Register of Historic Places*.

The only historic site listed in the *National Register of Historic Places* in the Oak Ridge area is the Graphite Reactor Building at Oak Ridge National Laboratory. Constructed during World War II as part of the Manhattan Project, the Graphite Reactor is the world's oldest existing nuclear reactor and is now open to the public on a routine basis.

3.10.2 Archaeological

An earlier archaeological survey⁴⁹ of the Oak Ridge reservation was conducted by the Department of Anthropology, University of Tennessee, Knoxville, from March 15 to June 30, 1974. Sites of aboriginal occupation that might be affected by future activities on the reservation were located and evaluated.

Reconnaissance and testing were done in several different physiographic zones, including the Clinch River and its larger tributary-stream terraces, the interior valleys, selected forested ridges, and specific facility areas. Previously recorded sites, known but unrecorded sites, and previously unknown sites were investigated. The survey techniques included collecting surface artifactual materials, examining subsurface soil strata, and interviewing longtime residents and employees.

Altogether, 45 sites of prehistoric aboriginal occupation and several historic Euroamerican homestead sites were examined. The primary emphasis of the study was on the prehistoric sites. Most of the major archaeological periods in the eastern Tennessee chronological sequence were represented in the material collected during the survey. The sites were distributed along the drainage system of the Clinch River, with the majority located on the main stream. Several sites, however, were located on the tributary streams of Poplar Creek, East Fork of Poplar Creek, and White Oak Creek.⁴⁹

3.10.3 Cultural

The tremendous diversity of interests and activities of Oak Ridge is indicated by the number of organizations (nearly 300 currently) listed each year by the local newspaper. The Oak Ridge Civic Music Association schedules nationally known musicians during the fall and winter seasons. These performances are interspersed with concerts by the Oak Ridge Symphony Orchestra and the Oak Ridge Chorus, both directed by a professional conductor. In Knoxville, the University of Tennessee's University Concerts series brings Broadway shows, ballet companies, and noted personalities to the Knoxville Municipal Coliseum and Auditorium.

The Oak Ridge Playhouse is a community-wide activity, with its own theater, a professional director, and a business manager.

The Oak Ridge Art Center houses a gallery, a studio, and a gift shop. Both local and traveling art shows are on display almost continually at the Center, and courses are offered in ceramics, lithography, oils, watercolors, drawing, and sculpture.

The American Museum of Science and Energy is a major attraction for tourists in eastern Tennessee. The \$3.5 million building features models, movies, demonstrations, devices, and machines, all designed to describe and explain concepts relating to energy phenomena.

Another point of interest is the University of Tennessee Arboretum, which includes one of the Southeast's largest and most complete collections of trees and plants from the Appalachian region and serves as a living source of information about trees and shrubs.

3.10.4 Scenic

Oak Ridge is situated in the middle of scenic eastern Tennessee, surrounded by mountains, rivers, lakes, and heavily forested ridges. Within an hour's driving distance of Oak Ridge are 5 of the 22 reservoirs built by the Tennessee Valley Authority on the Tennessee River and its tributaries. These five reservoirs have a total shoreline of 3700 km and with other lakes and streams provide fishing, boating, swimming, and other water sports.

Oak Ridge is about 100 km from the nation's most visited national park, the Great Smoky Mountains. The park embraces about 200,000 ha in Tennessee and North Carolina.

Oak Ridge has four city-maintained parks: Chestnut Ridge (off Melton Lake Drive), Ridgewood Park (near the Municipal Building), Key Springs Park (off Outer Drive), and Scarboro Village Park (in the Scarboro community). In addition to municipal parks, Clark Center Park, developed by Union Carbide Corporation for its employees, offers boating, swimming, and other facilities.

A substantial part of the land in and around Oak Ridge is undeveloped. Currently there are about 510 ha in city-owned and an almost equal amount in institutionally owned open space. Open space in the urban area can be attributed partly to pockets in residential developments left open due to rough terrain; greenbelts along the urban fringe provide additional natural surroundings.

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4. ENVIRONMENTAL IMPACTS

4.1 RADIOLOGICAL IMPACTS

4.1.1 Impacts on man

4.1.1.1 Assessment methodology

Radiological impacts on man are assessed by calculating the radiation dose to the maximally exposed individual and to the population living within an 80-km radius of the HFEL site. Radionuclides released to the environment through airborne or aquatic means can result in exposure to man via several different pathways. Significant potential pathways for internal and external radiation exposure to man from radionuclides released by a nuclear facility are illustrated in Fig. 4.1.

Radiological impact is estimated as the 50-year radiation dose commitment to individuals or populations in units of millirems or person-rem per year of facility operation (the HFEL is expected to run for 5 years). The dose commitment is calculated for a specified intake of radionuclide and is defined as the total dose to a reference organ (resulting from one year of intake) that will accrue during the remaining lifetime of an individual. The exposed person is assumed to be an adult 20 years of age at the time of intake who will live to an age of 70 years. Thus the dose commitment is calculated by integrating the dose rate over a 50-year period; the result is called the 50-year dose commitment. In this report, dose and dose commitment are used interchangeably, and each implies a 50-year dose commitment. Doses to specific organs can vary considerably for internal exposure from ingested or inhaled materials because some radionuclides concentrate in certain organs of the body. Estimates of radiation dose to the total body and major organs are, therefore, considered for all pathways of internal exposure and are based on parameters applicable to an average adult.

Radiation doses to the internal organs of children in the population vary from those received by an average adult because of differences in radionuclide metabolism, organ size, and diet. Differences between the organ doses of a child and those of an average adult may be significant. The estimated atmosphere-forage-cow-milk pathway dose to the thyroid of a one-year-old child from radioiodine in milk is about five times that for an average adult.^{1,2}

Population dose estimates for the total body are sums of the total-body doses to individuals within 80 km of the plant. It is assumed that radiation dose to the total body is relatively independent of age;³ therefore person-rem estimates are based on total-body doses calculated for adults. Similarly, the population dose estimates for the various organs are the sums of specific organ doses of the individuals within 80 km of the plant. The person-organ-rem estimates are also based on adult organ doses.

Methodology for airborne effluents

The AIRDOS-II computer code⁴ was used to estimate 50-year dose commitments from effluents released to the atmosphere. The AIRDOS-II code is a FORTRAN III computer code that calculates

Fig. 4.1. Schematic representation of assessment methodology used to calculate the radiological impact upon man.

the dose commitment to individuals and populations for as many as 36 radionuclides released from one to six stacks. HFEL gaseous effluents are released from a stack at Building 7911 and a vent for combustible off-gases on the roof of Building 7930. Annual average meteorological data are supplied for the surrounding area as input to the computer code. Output data include ground-level concentrations in air and rates of deposition on ground and water surfaces for each radionuclide at various distances and directions from the release point. From these values, doses to man at each distance and direction specified are estimated for total body, gastrointestinal tract, bone, thyroid, lungs, muscle, kidneys, liver, spleen, testes, and ovaries through each of the five pathways depicted in Fig. 4.1. The dose calculations are made with the use of dose-conversion factors supplied as input data for each radionuclide and exposure mode. Dose-conversion factors for submersion in the gas-borne effluent, exposure to contaminated ground surface, and intake of radionuclides through inhalation and

ingestion are calculated by use of dosimetric criteria of the International Commission on Radiological Protection (ICRP) and other recognized authorities. These factors are computed and summarized in two computer codes, one for external exposure, EXREM-III,⁵ and one for internal exposure, INREM-II.⁶

Radioactive particulates are removed from the atmosphere and deposited on the ground through mechanisms of dry deposition and scavenging. Dry deposition, as used in this analysis, represents an integrated deposition of radioactive materials by processes of gravitational settling, adsorption, particle interception, diffusion, and chemical electrostatic effects and is calculated from the deposition velocity for a one-year time interval. Deposition velocity values for particles and reactive gases commonly range from 0.1 to 6.0 cm/sec.⁷ A scavenging coefficient of $2.0 \times 10^{-5} \text{ sec}^{-1}$ is used for particulates, ^3H , ^{14}C , and radioiodines.

Many of the basic incremental parameters used in AIRDOS-II are conservative; that is, values are chosen to maximize intake by man. Many factors that would reduce the radiation dose, such as shielding provided by dwellings and time spent away from the reference location, are not considered. It is assumed that an individual lives outdoors at the reference location 100% of the time. Moreover, in estimating the doses to individuals via ingestion of vegetables, beef, and milk, all the food consumed by the individual is assumed to be produced at the reference location specified in the calculation. Thus the dose estimates calculated by these methods are likely to be higher than the doses that would actually occur.

A summary of the assumptions, models, and codes used to estimate radiation doses is given in ORNL-4992.⁸

Oak Ridge National Laboratory is located in an area of relatively high average population density. The AIRDOS-II population dose calculation methodology includes provision for a specific and detailed numerical description of the population within a given radius of the Laboratory. The description used is based on an updated version of the 1970 U.S. census for the area and includes a population of approximately 690,000 individuals. This population is subdivided by residence within one of 16 wedges, visualized as radiating outward to a distance of 80 km from the Laboratory and centered on 16 compass points. The population is further subdivided by residence within one of ten concentric disks, visualized as centered on the Laboratory, with radii increasing to a maximum of 80 km.

Population dose estimates in this document are, therefore, based on summations of average doses to subpopulations residing within these 160 subdivisions, using conservative dose-estimation procedures as described.

Methodology for liquid effluents

The radiological impact of liquid effluents was assessed by calculating the dose to the maximally exposed individual from the release of radioactivity into White Oak Creek. As White Oak Creek has no public access but does flow into the Clinch River, the maximally exposed individual was assumed to obtain his drinking water and fish at the intersection of White Oak Creek and the Clinch River. The average annual flow of White Oak Creek and the Clinch River are $1.0 \times 10^{13} \text{ ml/year}$ and $4.1 \times 10^{15} \text{ ml/year}$, respectively, and instantaneous and complete mixing is assumed. The aquatic pathways (see Fig. 4.1) considered in calculating the dose to the individual included submersion in water (swimming) for 1% of the year, ingestion of fish (20 g/day), and ingestion

of drinking water (1.2 liters/day). Further assumptions, models, and codes used to estimate radiation doses from contaminated liquid effluents are discussed in ORNL-4992.⁸

4.1.1.2 Analysis of radiological effects from gel-sphere-pac process

Maximum individual dose commitments from gaseous effluents

The quantities of radionuclides released to the atmosphere from the gel-sphere-pac process are listed in Tables 2.3 and 2.4 for uranium-plutonium and ²³³U-thorium fuels respectively. The points of release are a stack at Building 7911 and a standpipe on the roof of Building 7930. Particulates are in the form of oxides, assumed to be 0.3 μ m in size and insoluble. The 7911 stack has a height of 76 m, a diameter of 1.5 m, and an effluent velocity of 9.3 m/sec. The 7930 standpipe is at a height of 20 m and has a diameter of 5.2 cm and an average effluent velocity of 0.44 m/sec.

Estimated maximum annual total-body and organ doses to individuals from airborne effluents released from both the stack at Building 7911 and the standpipe at Building 7930 are included in Table 4.1 for the three process fuel preparation routes. Based on these data, it is clear that the most significant exposures that would be likely to occur during operation of the HFEL are due to releases from the 7930 standpipe. The organs that receive doses comparable with or greater than the dose received by the total body are the ones considered significant for each case of fuel preparation.

A breakdown of the primary contributors to the total-body and organ doses for uranium-plutonium fuel processing via the gel-sphere-pac route is given in Table 4.2. The most significant radio-

Table 4.1. Maximum individual 50-year dose commitments to the total body and various organs from radioactivity released to the atmosphere during one year of HFEL operations^a

Fuel option and release point ^b	Dose commitment (millirems)					
	Total body	GI tract	Bone	Lungs	Liver	Spleen
Gel-sphere-pac and HTGR green fuel rod ^c						
U-Pu fuel						
7911 stack	5.7(-5) ^d	5.0(-5)	4.8(-4)	1.0(-4)	2.2(-4)	e
7930 standpipe	2.9(-3)	3.2(-3)	2.6(-2)	5.7(-3)	1.1(-2)	e
²³³ U-Th fuel						
7911 stack	1.4(-5)	1.1(-5)	1.6(-5)	1.7(-5)	e	1.5(-5)
7930 standpipe	5.3(-4)	4.4(-4)	6.2(-4)	6.8(-4)	e	5.6(-4)
Sphere-cal						
U-Pu fuel						
7911 stack	4.5(-5)	4.0(-5)	3.9(-4)	8.3(-5)	1.7(-4)	e
7930 standpipe	2.4(-3)	2.5(-3)	2.0(-2)	4.6(-3)	0.1(-2)	e
²³³ U-Th fuel						
7911 stack	1.1(-5)	9.0(-6)	1.2(-5)	1.4(-5)	e	1.2(-5)
7930 standpipe	4.3(-4)	3.5(-4)	5.0(-4)	5.4(-4)	e	4.6(-4)

^aHFEL is expected to operate for five years.

^bThe point of maximum exposure occurs 3660 m from the release points.

^cReleases, and, consequently, doses are the same for both processes.

^d5.7(-5) means 5.7×10^{-5} , etc.

^eThe organ receives a significantly smaller dose than that received by the total body and is not considered a critical organ.

Table 4.2. Primary contributors to the dose commitment to various organs for individuals exposed during HFEL operations: uranium-plutonium fuel (gel-sphere-pac, sphere-cal, and HTGR green fuel rod)

Radionuclide	Contribution to dose commitment (%)				
	Total body	GI tract	Bone	Lungs	Liver
7911 stack					
²³⁸ Pu	25	2	31	57	30
²³⁹ Pu	5	<1	6	9	6
²⁴⁰ Pu	6	<1	8	12	8
²⁴¹ Pu	33	2	45	6	42
²⁴² Pu	2	<1	2	3	1
²⁴⁴ Cm	4	<1	6	<1	6
⁶⁰ Co	24	23	3	12	5
¹⁰⁶ Ru	2	69	<1	1	<1
7930 standpipe					
²³⁸ Pu	27	1	31	59	31
²³⁹ Pu	5	<1	6	9	6
²⁴⁰ Pu	7	<1	8	12	8
²⁴¹ Pu	36	1	46	6	44
²⁴² Pu	2	<1	2	3	2
²⁴⁴ Cm	3	<1	4	<1	4
⁶⁰ Co	17	13	2	9	4
¹⁰⁶ Ru	3	81	<1	2	<1

nuclides contributing to the doses appear to be ²³⁸Pu, ²⁴¹Pu, ⁶⁰Co, and ¹⁰⁶Ru for both points of release.

Table 4.3 shows the contributions of the major exposure modes to the maximum annual total-body and organ dose estimates for uranium-plutonium fuel. Inhalation is the primary exposure pathway for the total body and all organs except the GI tract, which receives its highest dose from ingestion.

The primary contributors to the total-body and organ doses are listed in Table 4.4 for ²³³U-thorium fuel processing by the gel-sphere-pac route. The main contributors to the doses are ⁶⁰Co, ²³²U, and ²³³U for release of airborne effluents from both the 7930 standpipe and 7911 stack.

The contributions to the maximum annual total-body and organ doses from the major exposure modes are listed in Table 4.5 for ²³³U-thorium fuel. Contaminated surfaces resulting from 7911 stack and 7930 standpipe emissions are the primary mode of exposure for the total body and all organs.

Population dose commitments from gaseous effluents

Table 4.6 lists population doses to the total body and to various organs in person-rem, assuming a population of approximately 690,000 persons living within an 80-km radius of the release points.

For uranium-plutonium fuel processing, the bone receives the highest organ dose to the population for releases from both the 7911 stack and the 7930 standpipe (5.3×10^{-3} person-rem and 1.0×10^{-1} person-rem respectively). Inhalation is again the predominant exposure mode for the organs listed in Table 4.6 with the exception of the gastrointestinal tract, which receives

Table 4.3. Contribution of major modes of exposure to estimated 50-year dose commitments to the total body and various organs of individuals^a from radioactivity released to the atmosphere during one year of HFEL operations: uranium-plutonium fuel (gel-sphere-pac and HTGR green fuel rod routes)^b

Exposure mode	Dose (millirems)				
	Total body	GI tract	Bone	Lungs	Liver
7911 stack					
Inhalation ^c	3.8 (-5)	3.0 (-8)	4.2 (-4)	9.1 (-5)	1.8 (-4)
Submersion	4.5 (-10)	3.4 (-10)	4.9 (-10)	4.3 (-10)	3.8 (-10)
in air ^d					
Contaminated ground ^d	1.4 (-5)	1.1 (-5)	1.5 (-5)	1.3 (-5)	1.2 (-5)
Ingestion ^e	5.1 (-6)	3.9 (-5)	5.1 (-5)	1.1 (-7)	2.4 (-5)
Total	5.7 (-5)	5.0 (-5)	4.8 (-4)	1.0 (-4)	2.2 (-4)
7930 standpipe					
Inhalation	2.2 (-3)	2.4 (-6)	2.3 (-2)	5.2 (-3)	1.0 (-2)
Submersion	2.7 (-8)	2.0 (-8)	3.0 (-8)	2.5 (-8)	2.3 (-8)
in air					
Contaminated ground	5.2 (-4)	4.0 (-4)	5.6 (-4)	4.9 (-4)	4.4 (-4)
Ingestion	2.2 (-4)	2.8 (-3)	2.0 (-3)	5.2 (-6)	9.4 (-4)
Total	2.9 (-3)	3.2 (-3)	2.6 (-2)	5.7 (-3)	1.1 (-2)

^aThe point of maximum exposure occurs 3660 m from point of release.

^bReleases of radionuclides are the same for both gel-sphere-pac and HTGR green fuel rod processes. As a result, the doses are identical.

^cInhalation rate of 20 m³ of air per day; inhaled particles <10 μ m in diameter.

^dExposure is for 100% of time; no shielding.

^eAll food is assumed to be produced and consumed at location of dose calculation. Daily intakes are 0.25 kg of vegetables, 0.3 kg of beef, and 1.0 liter of milk.

Table 4.4. Primary contributors to the dose commitment to various organs for individuals exposed during HFEL operations: ²³³U-thorium fuel (gel-sphere-pac, sphere-cal, and HTGR green fuel rod processes)

Radionuclide	Contribution to dose commitment (%)				
	Total body	GI tract	Bone	Lungs	Spleen
7911 stack					
²³² U	2	1	7	8	<1
²³³ U	<1	<1	2	9	<1
²²⁰ Rn	<1	<1	<1	<1	<1
²¹² Pb ^a	<1	2	2	<1	<1
⁶⁰ Co	97	97	89	76	99
7930 standpipe					
²³² U	2	<1	8	11	<1
²³³ U	1	<1	3	12	<1
²²⁰ Rn	<1	<1	<1	<1	<1
²¹² Pb ^a	<1	<1	<1	2	<1
⁶⁰ Co	97	99	89	75	99

^a²²⁰Rn has a half-life ($T_{1/2}$) of 55 s; it decays to ²¹⁶Po ($T_{1/2}$ = 0.15 s), which, in turn, decays to ²¹²Pb ($T_{1/2}$ = 10.64 h).

its greatest dose via ingestion. The most important radionuclides for population exposure are again ²³⁸Pu, ²⁴¹Pu, ⁶⁰Co, and ¹⁰⁶Ru.

For ²³³U-thorium fuel, the lungs and bone receive the highest doses to the population for releases from the 7911 stack and 7930 standpipe. The lungs and bone receive 2.0×10^{-4} person-rem and 1.9×10^{-4} person-rem, respectively, resulting from the 7911 stack, while they each receive 3.5×10^{-3} person-rem as a result of 7930 standpipe releases (Table 4.6).

Table 4.5. Contribution of major modes of exposure to estimated 50-year dose commitments to the total body and various organs of individuals^a from radioactivity released to the atmosphere during one year of HFEL operations: ²³³U-thorium fuel (gel-sphere-pac route and HTGR green fuel rod route)^b

Exposure mode	Dose commitment (millirems)				
	Total body	GI tract	Bone	Lungs	Spleen
7911 stack					
Inhalation ^c	2.0 (-7) ^d	1.2 (-8)	6.8 (-7)	4.4 (-6)	3.6 (-8)
Submersion in air ^e	6.0 (-10)	4.0 (-10)	7.6 (-10)	5.5 (-10)	5.7 (-10)
Contaminated ground ^e	1.4 (-5)	1.0 (-5)	1.4 (-5)	1.3 (-5)	1.5 (-5)
Ingestion ^f	2.0 (-7)	1.3 (-6)	1.0 (-7)	7.3 (-8)	1.6 (-7)
Total	1.4 (-5)	1.1 (-5)	1.6 (-5)	1.7 (-5)	1.5 (-5)
7930 standpipe					
Inhalation	1.0 (-5)	4.1 (-7)	3.7 (-5)	1.9 (-4)	2.0 (-6)
Submersion in air	2.3 (-8)	1.7 (-8)	2.5 (-8)	2.1 (-8)	2.4 (-8)
Contaminated ground	5.2 (-4)	3.9 (-4)	5.5 (-4)	4.9 (-4)	5.6 (-4)
Ingestion	7.0 (-6)	4.5 (-5)	3.2 (-5)	2.8 (-6)	6.0 (-6)
Total	5.3 (-4)	4.4 (-4)	6.2 (-4)	6.8 (-4)	5.6 (-4)

^aThe point of maximum exposure occurs 3660 m from the point of release.

^bReleases of radionuclides are the same for both gel-sphere-pac and HTGR green fuel rod processes. As a result, the doses are identical.

^cInhalation rate of 20 m³ of air per day; inhaled particles <10 μm in diameter.

^d2.0 (-7) means 2.0 X 10⁻⁷, etc.

^eExposure is for 100% of time; no shielding.

^fAll food is assumed to be produced and consumed at location of dose calculation. Daily intakes are 0.25 kg of vegetables, 0.3 kg of beef, and 1.0 liter of milk.

Table 4.6. Population dose commitments^a to the total body and various organs from radioactivity released to the atmosphere during one year of HFEL operations

Release point	Dose commitment (person-rems)					
	Total body	GI tract	Bone	Lungs	Liver	Spleen
Gel-sphere-pac and HTGR green fuel rod						
U-Pu fuel						
7911 stack	6.4(-4) ^b	6.0(-4)	5.3(-3)	1.1(-3)	2.4(-3)	c
7930 standpipe	1.2(-2)	1.8(-2)	1.0(-1)	2.2(-2)	4.7(-2)	c
²³³U-Th fuel						
7911 stack	1.6(-4)	1.4(-4)	1.9(-4)	2.0(-4)	c	1.7(-4)
7930 standpipe	3.0(-3)	2.5(-3)	3.5(-3)	3.5(-3)	c	3.2(-3)
Sphere-cal						
U-Pu fuel						
7911 stack	5.1(-4)	4.8(-4)	4.2(-3)	8.8(-4)	1.9(-3)	c
7930 standpipe	9.6(-3)	1.4(-2)	8.0(-2)	1.8(-2)	3.8(-2)	c
²³³U-Th fuel						
7911 stack	1.3(-4)	1.1(-4)	1.5(-4)	1.6(-4)	c	1.4(-4)
7930 standpipe	2.4(-3)	2.0(-3)	2.8(-3)	2.8(-3)	c	2.6(-3)

^aA population of approximately 690,000 persons is assumed within 80 km of ORNL.

^b6.4(-4) means 6.4 X 10⁻⁴, etc.

^cThe organ receives a significantly smaller dose than that received by the total body and is not considered a critical organ.

Contaminated surfaces from both release points are the primary exposure mode for the total body and all organs. The most significant radionuclides for population exposure are again ^{60}Co , ^{232}U , and ^{233}U , with small contributions from ^{212}Pb (^{220}Rn daughter).

Individual dose commitments from liquid effluents

The annual releases of radioactivity into White Oak Creek and the resulting concentrations in the Clinch River are shown in Tables 4.7 and 4.8 for uranium-plutonium and ^{233}U -thorium fuels respectively.

The annual total-body and organ doses estimated for the individual exposed to the various aquatic pathways associated with the use of Clinch River water are presented in Table 4.9 for uranium-

Table 4.7. Annual release of radionuclides in the liquid effluents and concentrations in Clinch River as a result of uranium-plutonium fuel preparation operations: gel-sphere-pac route

Radionuclide	Annual release to White Oak Creek ($\mu\text{Ci}/\text{year}$)	Concentration in Clinch River ^a ($\mu\text{Ci}/\text{ml}$)
^{234}U	8.1 (-5) ^b	2.0 (-20)
^{235}U	1.6 (-6)	4.0 (-22)
^{236}U	2.4 (-5)	5.8 (-21)
^{238}U	2.9 (-5)	7.1 (-21)
^{238}Pu	3.8	9.4 (-16)
^{239}Pu	6.4 (-1)	1.6 (-16)
^{240}Pu	8.5 (-1)	2.1 (-16)
^{241}Pu	2.1 (2)	5.1 (-14)
^{242}Pu	2.1 (-1)	5.2 (-17)
^{242}Cm	4.9 (-5)	1.2 (-20)
^{244}Cm	4.9 (-3)	1.2 (-18)
^{60}Co	5.1	1.3 (-15)
^{95}Zr	2.5	6.2 (-16)
^{95}Nb	1.8	4.2 (-16)
^{103}Ru	8.8	2.1 (-15)
^{106}Rh	4.1 (1)	1.0 (-14)
^{134}Cs	1.6 (2)	3.9 (-14)
^{137}Cs	1.8 (1)	1.9 (-14)
^{144}Ce	2.4	5.9 (-16)
^{154}Eu	3.9 (-2)	9.5 (-18)

^aThe annual flow of the Clinch River is assumed to be 4.1×10^{15} ml/year, with complete mixing in the river at the point of dose calculations.

^b8.1 (-5) means 8.1×10^{-5} , etc.

Table 4.8. Annual release of radionuclides in the liquid effluents and concentrations in the Clinch River as a result of U-233-thorium fuel preparation operations: gel-sphere-pac route

Radionuclide	Annual release to White Oak Creek ($\mu\text{Ci}/\text{year}$)	Concentration in Clinch River ^a ($\mu\text{Ci}/\text{ml}$)
^{232}U	5.7 (-2) ^b	1.4 (-17)
^{233}U	1.1 (-1)	2.7 (-17)
^{239}Pu	1.4 (-5)	3.4 (-21)
^{228}Th	1.8 (-6)	4.4 (-22)
^{232}Th	9.4 (-6)	2.3 (-21)
^{60}Co	5.2	1.3 (-15)

^aThe annual flow of the Clinch River is assumed to be 4.1×10^{15} ml/year. Assumes complete mixing in the river at the point of dose calculations.

^b5.7 (-2) means 5.7×10^{-2} , etc.

plutonium fuel. The primary exposure pathway for the total-body dose was the ingestion of fish (85%), due mainly to ^{134}Cs (76%) and ^{137}Cs (22%). Drinking contaminated water from the Clinch River was responsible for 13% of the total-body dose, with ^{134}Cs and ^{137}Cs , again, the critical radionuclides (76% and 21% respectively). The dose from swimming contributed less than 1% of the total-body and organ doses. The highest organ doses were to the bone (1.6×10^{-5} millirem/year) and the kidney (8.8×10^{-6} millirem/year). The major contributors to the bone dose from ingestion of both water and fish were ^{134}Cs and ^{137}Cs (about 38% and 30% respectively). The kidney dose was also due predominantly to ^{134}Cs and ^{137}Cs (about 66% and 28% respectively) from both water and fish consumption. All other organ doses are equal to or less than the total-body dose.

Annual total-body and organ doses from liquid wastes resulting from ^{233}U -thorium fuel preparation via the gel-sphere-pac route were estimated for the maximally exposed individual (Table 4.10). The critical exposure pathway for the total-body dose was the ingestion of water (76%), due primarily to ^{60}Co (93%), with a small contribution from ^{232}U (6%). Eating fish taken from the

Table 4.9. Annual doses^a to the individual from the liquid effluents^b released into the Clinch River from uranium-plutonium fuel pin production gel-sphere-pac route

Pathway	Dose (millirems/year)		
	Total body	Bone	Kidney
Submersion in water ^c	9.8(-11) ^d	1.1(-10)	8.9(-11)
Eating fish ^e	1.1(-5)	1.4(-5)	7.6(-6)
Drinking water ^f	1.7(-6)	2.3(-6)	1.2(-6)
Total	1.3(-5)	1.6(-5)	8.8(-6)

^a50-year dose commitments from one year's intake.

^bIncludes effluents discharged directly into White Oak Creek and diluted by Clinch River.

^cSwimming in water 1% of the year.

^d9.8(-11) means 9.8×10^{-11} , etc.

^eDaily intake of 20 g of fish caught in the Clinch River is assumed.

^fDaily intake of 1.2 liters of untreated water from the Clinch River is assumed.

Table 4.10. Annual doses^a to the individual from the liquid effluents^b released into the Clinch River from ^{233}U -thorium fuel pin production gel-sphere-pac route

Pathway	Dose (millirems/year)		
	Total body	Bone	Kidney
Submersion in water ^c	5.2(-12) ^d	5.5(-12)	4.1(-12)
Eating fish ^e	8.9(-9)	1.1(-8)	9.9(-10)
Drinking water ^f	2.8(-8)	6.2(-8)	5.5(-9)
Total	3.7(-8)	7.3(-8)	6.5(-9)

^a50-year dose commitments from one year's intake.

^bIncludes effluents discharged directly into White Oak Creek and diluted by Clinch River.

^cSwimming in water 1% of the year.

^d5.2(-12) means 5.2×10^{-12} , etc.

^eDaily intake of 20 g of fish caught in the Clinch River is assumed.

^fDaily intake of 1.2 liters of untreated water from the Clinch River is assumed.

Clinch River was responsible for 24% of the total-body dose. Swimming contributed about 1% of the total-body and organ doses. The most critical organ doses were to the bone (7.3×10^{-8} millirem/year) and kidney (7.0×10^{-9} millirem/year). The predominant radionuclides contributing to the bone dose from drinking water were ^{60}Co (42%), ^{232}U (42%), and ^{233}U (16%), while the kidney dose was attributed mainly to ^{232}U (49%) and ^{233}U (43%). The bone dose from eating fish was due primarily to ^{60}Co (77%) and ^{233}U (16%), while the kidney dose was from ^{232}U (44%) and ^{233}U (40%). All other organ doses are equal to or less than the total-body dose.

4.1.1.3 Analysis of radiological effects from sphere-cal process

Maximum individual dose commitment from gaseous effluents

The quantities of radionuclides released (weekly) to the atmosphere from the sphere-cal process are listed in Table 2.9. It is seen that the quantities released are less than for the gel-sphere-pac process (0.8 times those values). The resulting estimated maximum annual total-body and organ doses to individuals from these airborne effluents from both the stack at Building 7911 and the standpipe on Building 7930 are given in Table 4.1. The data show that exposures resulting from discharges from the 7930 standpipe are significantly greater than those from the 7911 stack.

The principal radionuclides giving rise to the total-body and organ doses during uranium-plutonium fuel particle preparation for the sphere-cal route are listed in Table 4.2 as to their percent contribution. The most significant nuclide giving rise to the total-body and organ doses resulting from both 7911 stack and 7930 standpipe emissions are ^{241}Pu , ^{238}Pu , and ^{60}Co .

Table 4.11 shows the contributions of the major exposure modes to the estimated maximum annual total-body and organ doses for uranium-plutonium fuel. The total body and organs receive their highest doses via inhalation except for the gastrointestinal tract, which receives its greatest doses through ingestion.

For ^{233}U -thorium fuel preparation via the sphere-cal route, the predominant radionuclide is ^{60}Co , with ^{232}U and ^{233}U contributing smaller amounts to the dose, as shown in Table 4.4. Contributions to the maximum annual total-body and organ doses for ^{233}U -thorium fuel preparation from the major exposure modes are listed in Table 4.12. Contaminated surfaces resulting from both 7911 stack and 7930 standpipe emissions is the primary exposure pathway for the total body and all organs.

Population dose commitments from gaseous effluents

Table 4.6 lists population doses from the sphere-cal process to the total body and to various organs in person-rems, assuming a population of approximately 690,000 persons living within 80 km of the release points.

For uranium-plutonium fuel processing by the sphere-cal route, the bone receives the highest dose resulting from releases from both the 7911 stack and 7930 standpipe (4.2×10^{-3} person-rem and 8.0×10^{-2} person-rem respectively). Inhalation is the predominant exposure pathway for all organs except for the gastrointestinal tract, which receives its dose mainly from ingestion. Radionuclides of concern are ^{238}Pu , ^{241}Pu , ^{60}Co , and ^{106}Ru .

Table 4.11. Contribution of major modes of exposure to estimated 50-year dose commitments to the total body and various organs of individuals^a from radioactivity released to the atmosphere during one year of HFEL operations: uranium-plutonium fuel, sphere-cal route

Exposure mode	Dose (millirems)				
	Total body	GI tract	Bone	Lungs	Liver
7911 stack					
Inhalation ^b	3.0(-5) ^c	2.4(-8)	3.4(-4)	7.3(-5)	1.4(-4)
Submersion in air ^d	3.6(-10)	2.7(-10)	3.9(-10)	3.4(-10)	3.0(-10)
Contaminated ground ^d	1.1(-5)	8.8(-6)	1.2(-5)	1.0(-5)	9.6(-6)
Ingestion ^e	4.1(-6)	3.1(-5)	4.1(-5)	8.8(-8)	1.9(-5)
Total	4.5(-5)	4.0(-5)	3.9(-4)	8.3(-5)	1.7(-4)
7930 standpipe					
Inhalation	1.8(-3)	1.9(-6)	1.8(-2)	4.2(-3)	8.0(-3)
Submersion in air	2.2(-8)	1.6(-8)	2.4(-8)	2.0(-8)	1.8(-8)
Contaminated ground	4.2(-4)	3.2(-4)	4.5(-4)	3.9(-4)	3.5(-4)
Ingestion	1.8(-4)	2.2(-3)	1.6(-3)	4.2(-6)	7.5(-4)
Total	2.4(-3)	2.5(-3)	2.0(-2)	4.6(-3)	9.1(-3)

^aThe point of maximum exposure occurs 3660 m from point of release.

^bInhalation rate of 20 m³ of air per day; inhaled particles <10 μ m in diameter.

^c3.0(-5) means 3.0×10^{-5} , etc.

^dExposure is for 100% of time; no shielding.

^eAll food is assumed to be produced and consumed at location of dose calculation. Daily intakes are 0.25 kg of vegetables, 0.3 kg of beef, and 1.0 liter of milk.

For ²³³U-thorium fuel, the lung and bone receive the highest organ doses to the population for both 7911 stack and 7930 standpipe emissions, as shown in Table 4.6. Contaminated surfaces are the primary exposure pathway, with ⁶⁰Co, ²³²U, ²³³U the predominant radionuclides.

Individual dose commitments from liquid effluents

The weekly release of radioactivity into White Oak Creek from the sphere-cal process is indicated in Table 2.9. The annual releases and resulting concentrations in the Clinch River are shown in Tables 4.13 and 4.14 for uranium-plutonium and ²³³U-thorium fuels respectively.

The annual total-body and organ doses for an individual exposed to the various aquatic pathways are included in Table 4.15 for uranium-plutonium fuel preparation via the sphere-cal route. The doses are estimates based on radioactive discharges into the White Oak Creek and diluted by the Clinch River.

The predominant radionuclides giving rise to the total-body dose are ¹³⁴Cs and ¹³⁷Cs, with the primary exposure mode being fish ingestion (88%). Drinking contaminated water contributes 14% of the total-body dose. The highest organ doses were to the bone (1.3×10^{-5} millirem/year) and the kidney (7.1×10^{-6} millirem/year). Major radionuclides contributing to the bone dose and kidney dose from both fish and water ingestion are ¹³⁴Cs and ¹³⁷Cs.

For ²³³U-thorium fuel via the sphere-cal preparation route, the annual total-body and organ doses due to liquid effluents are presented in Table 4.16. The primary exposure pathway for the total-body dose is drinking water (73%), due mainly to ⁶⁰Co. Fish ingestion accounts for

Table 4.12. Contribution of major modes of exposure to estimated 50-year dose commitments to the total body and various organs of individuals^a from radioactivity released to the atmosphere during one year of HFEL operations: ²³³U-thorium fuel, sphere-cal route

Exposure mode	Dose (millirems)				
	Total body	GI tract	Bone	Lungs	Spleen
7911 stack					
Inhalation ^b	1.6(-7) ^c	9.6(-9)	5.4(-7)	3.5(-6)	2.9(-8)
Submersion in air ^d	4.8(-10)	3.2(-10)	6.1(-10)	4.4(-10)	4.6(-10)
Contaminated ground ^d	1.1(-5)	8.0(-6)	1.1(-5)	1.0(-5)	1.2(-5)
Ingestion ^e	1.6(-7)	1.0(-6)	8.0(-8)	5.8(-8)	1.3(-7)
Total	1.1(-5)	9.0(-6)	1.2(-5)	1.4(-5)	1.2(-5)
7930 standpipe					
Inhalation	8.0(-6)	3.3(-7)	3.0(-5)	1.5(-4)	1.6(-6)
Submersion in air	1.8(-8)	1.4(-8)	2.0(-8)	1.7(-8)	1.9(-8)
Contaminated ground	4.2(-4)	3.1(-4)	4.4(-4)	3.9(-4)	4.5(-4)
Ingestion	5.6(-6)	3.6(-5)	2.6(-5)	2.2(-6)	4.8(-6)
Total	4.3(-4)	3.5(-4)	5.0(-4)	5.4(-4)	4.6(-4)

^aThe point of maximum exposure occurs 3660 m from point of release.

^bInhalation rate of 20 m³ of air per day; inhaled particles <10 μm in diameter.

^c1.6(-7) means 1.6 X 10⁻⁷, etc.

^dExposure is for 100% of time; no shielding.

^eAll food is assumed to be produced and consumed at location of dose calculation. Daily intakes are 0.25 kg of vegetables, 0.3 kg of beef, and 1.0 liter of milk.

approximately 24% of the total-body dose. Swimming in contaminated water contributes about 1% to the dose. The highest organ doses are to the bone and kidney (5.9×10^{-10} millirem/year and 5.5×10^{-9} millirem/year respectively). The major radionuclides contributing to the bone dose are ⁶⁰Co, ²³²U, and ²³³U, while the kidney dose is due mainly to ²³²U and ²³³U from both fish and water ingestion.

4.1.1.4 Analysis of radiological effects from HTGR green fuel rod process

Maximum individual dose commitment from gaseous effluents

The quantities of radionuclides released to the environment from the HTGR green fuel rod process are indicated in Table 2.10. The atmospheric releases are the same as for the gel-sphere-pac process (see Sect. 4.1.1.2). As a result, the doses to the total body and organs are the same for the two processes and are given in Table 4.1. Contributions to the dose from the various exposure modes for the HTGR green fuel rod process are included in Tables 4.2-4.5 for both fuel options (uranium-plutonium and ²³³U-thorium).

Population dose commitments from gaseous effluents

The quantities of radionuclides released to the atmosphere during the processing of both uranium-plutonium fuel and ²³³U-thorium fuel via the HTGR green fuel rod route are the same as those released via the gel-sphere-pac route (see Table 2.10). Consequently, the population doses are the same for both processes and are included in Table 4.6. For additional discussion see Sect. 4.1.1.2.

Table 4.13. Annual release of radionuclides in the liquid effluents and concentrations in Clinch River as a result of uranium-plutonium fuel preparation operation: sphere-cal route

Radionuclide	Annual release to White Oak Creek ($\mu\text{Ci}/\text{year}$)	Concentration in Clinch River ($\mu\text{Ci}/\text{ml}$) ^a
²³⁴ U	6.5(-5) ^b	1.6(-20)
²³⁵ U	1.3(-6)	3.2(-22)
²³⁶ U	1.9(-5)	4.6(-21)
²³⁸ U	2.3(-5)	5.7(-21)
²³⁸ Pu	3.0	7.5(-16)
²³⁹ Pu	5.1(-1)	1.3(-16)
²⁴⁰ Pu	6.8(-1)	1.7(-16)
²⁴¹ Pu	1.7(2)	4.1(-14)
²⁴² Pu	1.7(-1)	4.2(-17)
²⁴² Cm	3.9(-5)	9.6(-21)
²⁴⁴ Cm	3.9(-3)	9.6(-19)
⁶⁰ Co	4.1	1.0(-15)
⁹⁵ Zr	2.0	5.0(-16)
⁹⁵ Nb	1.4	3.4(-16)
¹⁰³ Ru	7.0	1.7(-15)
¹⁰⁶ Ru	3.3(1)	8.0(-15)
¹³⁴ Cs	1.3(2)	3.1(-14)
¹³⁷ Cs	6.2(1)	1.5(-14)
¹⁴⁴ Ce	1.9	4.7(-16)
¹⁵⁴ Eu	3.1(-2)	7.6(-18)

^aThe annual flow of the Clinch River is assumed to be 4.1×10^{15} ml/year, with complete mixing in the river at the point of dose calculations.

^b6.5(-5) means 6.5×10^{-5} , etc.

Table 4.14. Annual release of radionuclides in the liquid effluents and concentrations^a in the Clinch River as a result of ²³³U-thorium fuel preparation operations: sphere-cal route

Radionuclide	Annual release to White Oak Creek ($\mu\text{Ci}/\text{year}$)	Concentration in Clinch River ($\mu\text{Ci}/\text{ml}$) ^b
²³² U	4.6(-2) ^c	1.1(-17)
²³³ U	8.8(-2)	2.2(-17)
²³⁹ Pu	1.1(-5)	2.7(-21)
²²⁸ Th	1.4(-6)	3.5(-22)
²³² Th	1.0(-5)	2.5(-21)
⁶⁰ Co	4.2	1.0(-16)

^aThe annual flow of the Clinch River is assumed to be 4.1×10^{15} ml/year.

^bAssumes complete mixing in the river at the point of dose calculations.

^c4.6(-2) means 4.6×10^{-2} , etc.

Table 4.15. Annual doses^a to the individual from the liquid effluents^b released into the Clinch River from uranium-plutonium fuel preparation: sphere-cal route

Pathway	Dose (millirems/year)		
	Total body	Bone	Kidney
Submersion in water ^c	7.8(-11) ^d	8.8(-11)	7.1(-11)
Eating fish ^e	8.8(-6)	1.1(-5)	6.1(-6)
Drinking water ^f	1.4(-6)	1.8(-6)	9.6(-7)
Total	1.0(-5)	1.3(-5)	7.1(-6)

^a50-year dose commitments from one year's intake.

^bIncludes effluents discharged directly into White Oak Creek and diluted by the Clinch River.

^cSwimming in water 1% of the year.

^d7.8(-11) means 7.8×10^{-11} , etc.

^eDaily intake of 20 g of fish caught in the Clinch River is assumed.

^fDaily intake of 1.2 liters of untreated water from the Clinch River is assumed.

Table 4.16. Annual doses^a to the individual from the liquid effluents^b released into Clinch River from ²³³U-thorium fuel preparation: sphere-cal route

Pathway	Dose (millirems/year)		
	Total body	Bone	Kidney
Submersion in water ^c	4.2(-12) ^d	4.4(-12)	3.3(-12)
Eating fish ^e	7.1(-9)	8.8(-9)	7.9(-10)
Drinking water ^f	2.2(-8)	5.0(-8)	4.4(-9)
Total	3.0(-8)	5.9(-8)	5.2(-9)

^a50-year dose commitments from one year's intake.

^bIncludes effluents discharged directly into White Oak Creek and diluted by the Clinch River.

^cSwimming in water 1% of the year.

^d4.2(-12) means 4.2×10^{-12} , etc.

^eDaily intake of 20 g of fish caught in the Clinch River is assumed.

^fDaily intake of 1.2 liters of untreated water from the Clinch River is assumed.

Individual dose commitments from liquid effluents

Table 2.10 indicates that the release of radioactivity to White Oak Creek from the HTGR green fuel rod process is 10% greater than for the gel-sphere-pac process. As a result, for the HTGR green fuel rod process, the quantity of radioactivity released to White Oak Creek annually and the resulting concentrations in the Clinch River are 10% greater than those shown in Tables 4.7 and 4.8. Likewise, doses to individuals from aquatic pathways shown in Fig. 4.1 are 10% greater than the values for the gel-sphere-pac process shown in Tables 4.9 and 4.10. See Sect. 4.1.1.2 for a discussion of the gel-sphere-pac process.

4.1.1.5 Radiological impact comparison of HFEL processes

For assessment purposes, it has been assumed that the annual releases of radioactivity from each process are for 52 weeks of continuous operation. This gives the maximum possible yearly release for each process involved. However, two different processes will not be operating simultaneously, and the most probable mode of operation will be for one process to run from one to several weeks, to be followed by a different process using the same or different fuel for another period of several weeks. There may be downtime between runs when no discharges are made. Thus actual

operation will probably be some mix of the various processes running consecutively throughout the year.

The base case is considered to be the gel-sphere-pac fuel pin fabrication process. Two variations from this process are also considered: option 1, the sphere-cal fuel pin fabrication process, and option 2, the HTGR green fuel rod fabrication process. The radiological impacts for the three processes are not greatly different. Table 4.17 gives a comparison for the three, assuming the gel-sphere-pac process to be unity.

The maximum individual dose commitments for the gaseous effluents are well below the present Nuclear Regulatory Commission regulations (10 CFR Part 20) of 500 millirems to the total body, 3000 millirems to the bone, and 1500 millirems to the lungs. Additionally, all annual doses are below future EPA standards (40 CFR Part 190) for annual doses of 25 millirems to the total body, 75 millirems to the thyroid, and 25 millirems to all other organs. The estimated population dose commitments for total-body doses are substantially lower (by factors of more than 10^6) than the corresponding population dose resulting from the natural background of the State of Tennessee⁹ (approximately 70,000 person-rems).

Regardless of the fuel preparation operation, the doses from all aquatic pathways to the total body and organs were significantly lower than 1 millirem/year and do not add much to the total dose of the individual. All doses from the Clinch River are well below the future EPA limits of 25 millirems/year for the total body, bone, and kidney (40 CFR 190).

4.1.2 Impacts on biota other than man

No adequate methodology exists for the estimation of cumulative doses to terrestrial animals; therefore doses have not been estimated in this report. It may be generally assumed, however, that the radiosensitivity of organisms other than man is less than that for man himself and that if man is protected from the potentially harmful effects of radiation, other organisms will also be protected.

Because no direct liquid radionuclide releases from the HFEL facilities occur during normal operations, the potential for impact via liquid effluents needs to be assessed only for materials calculated to pass through the ORNL Intermediate-Level Waste (ILW) System. Carryover of radionuclides into the condensate of the ILW evaporator is conservatively estimated to result in a decontamination factor (DF) of 10^7 . This DF is assumed to be nonspecific with

Table 4.17. Relative radiological impacts

Process	Fuel type	Gaseous impact	Liquid impact	Solid impact
Gel-sphere-pac ^a	U/Pu	1	1	1
	²³³ U/Th	1	1	1
Sphere-cal	U/Pu	0.8	0.8	0.8
	²³³ U/Th	0.8	0.8	0.8
HTGR green fuel rod	U/Pu	1	1.1	1.7
	²³³ U/Th	1	1.1	1.7

^a Gel-sphere-pac impacts set at unity.

respect to the radionuclides listed and results in the estimates of annual radionuclide releases to White Oak Creek given in Tables 4.7 and 4.8.

Assuming annual flows of 10^{13} ml in White Oak Creek and 4.1×10^{15} ml in the Clinch River and making the assumption of complete mixing in the river, resulting radionuclide concentrations are listed in Tables 4.7 and 4.8.

To estimate the hazard level of these radionuclide concentrations, reference is made to the ERDA manual "Standards for Radiation Protection," Chapter 0524 (April 1975). Comparisons made to limiting waterborne radionuclide concentrations listed in this manual for population groups in uncontrolled areas indicate very low estimated concentrations relative to their respective standards.

Department of Energy standards for radiation protection are therefore not expected to be exceeded by HFEL-related liquid releases, even under conservative conditions.

4.2 NONRADIOLOGICAL IMPACTS

4.2.1 Impacts of construction

Because the HFEL will be located in an existing building at ORNL, there will be no significant impacts on land use. Probably only a very small area immediately surrounding the building will be adversely impacted by construction activities. There are no rare or endangered species in the vicinity that would be affected.

Runoff from the construction site will very likely contain suspended sediments that will increase the turbidity of receiving streams. This impact is not considered significant because of the small size of the land area that will be disturbed. Practices to control sediment-laden runoff from the site may be employed.

4.2.2 Impacts of operation

No direct operational discharges of liquid effluents to surface streams are anticipated (Sect. 2.2.3). Discharges from all three processes will be through the ORNL Intermediate Level Waste Facility, which treats the wastes before discharge. Therefore the increments of pollution resulting from HFEL operation should be minor and should have no significant effect on water use and aquatic ecosystems.

Gaseous emissions are given in Tables 2.3, 2.4, 2.9, and 2.10. These tables present data for all three processes that may be used in the facility. Only one process will be run at any one time, and only one fuel will be used at any one time. Therefore, for a conservative assessment, the staff uses only the data for the HTGR green fuel rod fabrication process (Table 2.10), which, if used for the entire year, would result in the greatest amount of gaseous emissions as compared with the other two processes. Because of the minor amounts of emissions predicted (Table 2.10), there will be no significant land use or ecological impacts resulting from these emissions. To illustrate, if it is assumed that the total annual emissions would be contained within 0.5 km of the site and within an altitude of 100 m, the following concentrations of emissions would result: argon, 56 ppm; hydrogen, 5.8 ppm; helium, 5.6 ppm; propene, 0.6 ppm; acetylene, 0.1 ppm, perchloroethylene, 0.1 ppm; hydrogen chloride, 0.003 ppm; ammonia, 0.001 ppm; and methyltrichlorosilane, 0.0003 ppm. In reality, these emissions will be dispersed throughout

a much larger volume, and the concentrations will be much lower. Therefore there will be no significant ecological or land use impacts from gaseous emissions locally or in a larger area.

4.3 COMMUNITY EFFECTS

Modifications and additions to TURF at ORNL will require a total of 127 person-years of work over a three-year period (1983 to 1985). The peak labor requirement will occur in 1984, when a total of 55 construction personnel will be employed.

Operation of the test facility will employ 4 to 33 people from 1983 to 1987. This should not result in an increase in employment because most of the positions will be filled by current ORNL staff. The total construction and operation personnel requirements are small compared with the existing DOE work force and the area population (Sect. 3.7); therefore no detectable impacts on the area communities should be caused by the work force.

A breakdown of the manpower needs by fiscal year is given below:

<u>Item</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>1986</u>	<u>1987</u>
Construction					
Facility	34	30	8		
Equipment	9	25	21		
Subtotal	43	55	29		
Operational subtotal	4	12	30	33	33
Total	47	67	59	33	33

Because the DOE facilities are tax-exempt, construction and operation of the test facility will not result in any direct tax payments.

REFERENCES FOR SECTION 4

1. J. K. Soldat, "Environmental Evaluation of an Acute Release of ^{131}I to the Atmosphere," *Health Phys.* 11: 1009 (1966).
2. B. Shleien, "An Evaluation of Internal Radiation Exposure Based on Dose Commitments from Radionuclides in Milk, Food, and Air," *Health Phys.* 18: 267 (1970).
3. Federal Radiation Council, *Estimates and Evaluation of Fallout in the United States from Nuclear Weapons Testing Conducted through 1962*, Report No. 4, U.S. Government Printing Office, Washington, D.C., May 1963.
4. R. E. Moore, *The AIRDOS-II Computer Code for Estimating Radiation Dose to Man from Airborne Radionuclides in Areas Surrounding Nuclear Facilities*, ORNL-5245, Oak Ridge National Laboratory, April 1977.
5. D. K. Trubey and S. V. Kaye, *The EXREM-III Computer Code for Estimating External Radiation Doses to Populations from Environmental Releases*, ORNL/TM-4322, Oak Ridge National Laboratory, Oak Ridge, Tenn., December 1973.
6. G. G. Killough, D. E. Dunning, Jr., and J. C. Pleasant, *INREM II: A Computer Implementation of Recent Models for Estimating the Dose Equivalent to Organs of Man from an Inhaled or Ingested Radionuclide*, NUREG/CR-0114, ORNL/NUREG/TM-84, Oak Ridge National Laboratory, Oak Ridge, Tenn., June 1978.
7. D. H. Slade, *Meteorology and Atomic Energy*, TID-24190, U.S. Atomic Energy Commission, Oak Ridge, Tenn., 1968.
8. G. G. Killough and L. R. McKay, eds., *A Methodology for Calculating Radiation Doses from Radioactivity Released to the Environment*, ORNL-4992, Oak Ridge National Laboratory, Oak Ridge, Tenn., March 1976.
9. D. T. Oakley, *Natural Radiation Exposure in the United States*, U.S. Environmental Protection Agency, ORP/SID 72-1, Washington, D.C., June 1972.

5. UNAVOIDABLE ADVERSE ENVIRONMENTAL EFFECTS

The HFEL will require only a minimum of construction activity, not exceeding normal construction routinely occurring at ORNL (Sect. 4.2). Therefore no significant adverse effects are expected from such construction on land and water use or on aquatic and terrestrial ecosystems.

Gaseous effluents to be released during the routine operation of the HFEL are argon, ammonia, helium, hydrogen, acetylene, propene, perchloroethylene, methyltrichlorosilane, and hydrogen chloride (Table 2.10). The amounts to be released are very small, and no adverse impacts should occur (Sect. 4.2). No direct operational releases of liquid effluents are planned to be made to surface or groundwaters; the small incremental releases from the HFEL will result in no significant impacts on water use or on aquatic ecosystems (Sect. 4.2).

The maximum individual total-body dose commitment from gaseous releases from normal operations is 2.9×10^{-3} millirems and the maximum population dose commitment for the population living within 80 km of the facility is 1.2×10^{-2} person-rems. The maximum individual dose commitment from liquid releases is 1.5×10^{-5} millirems. These dose commitments are very small and no significant radiological impacts are expected from these routine releases.

6. IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

Those resources that might be irreversibly committed or rendered irretrievable by the HFEL include (1) biological species destroyed, (2) construction materials that cannot be recovered, (3) materials rendered radioactive that cannot be decontaminated, (4) materials consumed or converted to unrecoverable waste, (5) atmosphere and water bodies used for disposal of heat and waste effluents to the extent that other beneficial uses are curtailed, (6) land areas rendered unfit for other uses, and (7) manpower resources.

Significant impacts are not expected from construction or routine operation of the project. Therefore effects on biological organisms will be minimal. Discharges to the atmosphere and water bodies will not render them unfit for other uses. Only a limited quantity of materials will be used for alterations to TURF. Some material will be rendered radioactive and will require disposal. The construction work effort will total 127 person-years (over a three-year period), and operation of the facility will require up to 22 persons for five years. These manpower needs are small compared with the average active work force at ORNL.

No large quantities of strategic or rare resources are to be consumed or rendered useless by the project. The facility itself will probably be useful to future projects at ORNL and will therefore not become obsolete upon completion of the proposed HFEL work.

7. RELATIONSHIP OF LAND-USE PLANS, POLICIES, AND CONTROLS

The Department of Energy's Oak Ridge Reservation presently consists of about 15,000 ha. The reservation is land that has been retained to accommodate projects of interest to the Federal Government, such as the HFEL. The HFEL operations will be confined to the area inside the reservation designated for ORNL use. No conflicts presently exist between DOE's current use of this land and local land-use plans or policies. There is no reason to expect any future conflicts.

In 1976, the Division of Water Quality Control of the Tennessee Department of Public Health published the official State Water Quality Management Plan for the Clinch River Basin. The material quoted below is taken from this report.¹

The presence of various radionuclides in the Clinch River downstream of its tributaries, White Oak Creek and Poplar Creek, has been noted for many years and studied in detail. Monitoring has been recently undertaken of waters above and below the confluence with White Oak Creek by the Tennessee Division of Occupational and Radiological Health, and by the U.S. Energy Research and Development Administration in conjunction with the proposed location of a breeder reactor plant near mile 18. A summary of these data is shown in Table 16, with the State water quality standards for each parameter also listed.

The radiation standards of the State of Tennessee entitled "State Regulations for Protection Against Radiation" (SRPAR) and standards of the U.S. Nuclear Regulatory Commission (NRC) apply at the location where a waste stream enters an unrestricted area. In this particular instance it is the confluence of White Oak Creek with the Clinch River. Under normal circumstances, i.e., with the State or NRC regulating contamination to a stream by private industry, such effluents as those released by the Oak Ridge National Laboratory via White Oak Creek would be required to conform to State or NRC standards prior to any mixing with the Clinch River.

However, as the Oak Ridge National Laboratory is a prime contractor of the Federal Government, it claims to be exempt from State regulations in respect to radioactive releases. Therefore, all the Oak Ridge facilities, designated as prime contractors, are regulated by separate and less stringent regulations adopted by the U.S. Energy Research and Development Administration (ERDA). These regulations are identified as Chapter 0524, "Standards for Radiation Protection." These ERDA regulations permit discharges to state streams as long as "average concentrations of radioactive material at the point of release are as low as practicable."

Monitoring data released by ERDA thus far appear to indicate that State standards are not being violated by the Oak Ridge facilities in their releases to the Clinch River. However, ERDA data published for the White Oak Creek discharge point takes credit for the dilution of the O.R.N.L. waste with the average flow of the entire Clinch River. Thus, ERDA monitoring data for this point is not reported as direct measurements of effluents released but as calculated numbers which take into account the ratio of the flow rates of the two streams. Neither State nor NRC regulations permit such manipulation of radioactivity data.

In order for citizens of Tennessee to be afforded the same protection from ERDA-regulated facilities as they are from State- and NRC-regulated private industry, it is recommended that ERDA further cooperate with the state by limiting the radioactive releases from its facilities, and not take advantage of the lenient requirements of its own regulations.

Because it is extremely difficult to monitor the effluents directly as they leave the O.R.N.L. reservation via White Oak Creek due to periods of no flow and back flow conditions of the White Oak Creek embayment (these flow conditions exist at certain times due to river level fluctuations caused by manipulations at Watts Bar and Melton Hill dams), the State will need to have direct access to monitoring data collected by ERDA at White Oak dam.¹

From the above, the discharges from ORNL appear to conflict with the Tennessee Water Quality Standards. We do not know of any measurements in the Clinch River that exceed State standards for concentrations of radionuclides and do not see any real conflict. The HFEL effluents will contribute to the ORNL discharges but will be only a small part of the total.

REFERENCE FOR SECTION 7

1. Tennessee Department of Public Health Division of Water Quality Control, *Water Quality Management Plan for the Clinch River Basin*, Oct. 27, 1976, pp. V-8, V-9.

8. RELATIONSHIP BETWEEN SHORT-TERM USES AND LONG-TERM PRODUCTIVITY

Since the HFEL will operate for only a five-year period, it will result in a short-term use of the facilities. Because of the minimal amount of construction necessary for the project, there will be only a small amount of land and construction resources that will be unavailable for other uses. The project will use facilities that are now largely unused or underused, and renovations of these facilities to accommodate the project will be useful for later projects conducted at ORNL.

No significant alterations to the environment around the HFEL site are expected; therefore no loss in long-term productivity of these areas should occur.

No critical resources will be consumed or rendered useless by the project that would limit the productivity of future operations employing those resources.

9. ENVIRONMENTAL TRADE-OFF ANALYSIS

Section 2 of this Environmental Statement has described the proposal to modify and equip an existing building at Oak Ridge National Laboratory for developing the technology of nuclear fuel fabrication from component fuel and nonfuel mixes that offer less risk of nuclear weapons proliferation. The proposed program, Hot Fuels Engineering Laboratory (HFEL), will involve the remote processing of uranium-plutonium or uranium-thorium fuels containing a variety of fission products and radioactive ^{60}Co added as a major spikant followed by remote fabrication of fuel pins and rods for existing types of reactors. This program is fundamental to the development and demonstration of the engineering equipment and its integration with the previously proven chemical process technology base. Section 2 also contains a description of the relatively small amount of materials consumed in the process, as well as the effluents released to the environment during the proposed five years of operation (Sect. 2.2.3).

Section 3 describes the site location and characterizes the existing environment around the proposed site. This environmental description provides the baseline upon which environmental impacts of the proposed action are evaluated.

Section 4 analyzes the environmental impacts of the proposed action. Because the proposal consists of modification and use of an existing building at ORNL, the staff has concluded that there is very little impact of construction on land or water use or on terrestrial and aquatic ecosystems (Sect. 4.2). In addition, the project's construction work force (maximum of 55) is expected to be only a portion of the construction manpower that is employed on the Department of Energy reservation.

With respect to operation, the maximum nonradiological effluents that will be released from HFEL are shown in Table 2.10. This effluent release is not expected to cause any significant environmental impact. The principal impact of HFEL operation will be the addition of radioactive material to the environment. Table 9.1 is a summary of the staff analysis for the maximum radiological impact on man (Sect. 4.1.1) resulting from gaseous releases due to the proposed action for both the maximally exposed individual and the total population within 80 km of the site. The calculated exposures are no more than 1% of the estimated exposures

Table 9.1. Radiological impact on man resulting from one year of HFEL operational gaseous effluent^a

	Total body	GI tract	Bone	Lungs	Liver	Spleen
Maximum individual 50-year dose commitments, millirems	2.9(-3) ^b	3.2(-3)	2.6(-2)	5.7(-3)	1.1(-2)	5.6(-4)
Population 50-year dose commitments, person-rems	1.2(-2)	1.8(-2)	1.0(-1)	2.7(-2)	4.7(-2)	3.2(-3)

^a Assumes most adverse fuel option and most adverse process.

^b 2.9(-3) is interpreted as 2.9×10^{-3} .

as a result of all ORNL operations.¹ The impacts of radioactive gaseous effluents due to HFEL operation were found to be considerably less than the permissible individual dose commitments in current Nuclear Regulatory Commission regulations (10 CFR 20) or in future Environmental Protection Agency standards (40 CFR 190). Finally, the population dose commitment to the total body is almost a factor of 10^7 less than the natural background population dose in Tennessee (about 70,000 person-rems). Assuming that the sensitivity to radioactivity of organisms other than man is no greater than for man himself, the staff concluded that other biota will not be adversely affected by HFEL-related gaseous effluents (Sect. 4.1.2).

Liquid radioactive effluents related to the HFEL contribute no more than about 10^{-5} millirem/year total-body dose to the maximally exposed individual at the intersection of White Oak Creek and the Clinch River. This dose is insignificant when compared with the future EPA limit of 25 millirems/year.

In summary, the staff finds that construction activities and operation of the proposed HFEL do not result in an unacceptable level of impacts on man or the natural environment.

Although finding the environmental impact of the proposed action to be acceptable, the staff did consider alternatives (Sect. 2.4) that would result in reduced or different impacts. These alternatives included cancellation or postponement of the project and relocation of the site.

The HFEL is a necessary development step in an existing National Program Plan for providing alternative nuclear fuel cycle capabilities with less risk of nuclear weapons proliferation. The resulting technology base will be used in the design and construction of a fabrication plant by the mid-1990s. Cancellation or major postponement of the HFEL program would jeopardize the timely objectives of the National Program Plan to develop technical readiness to fabricate nuclear fuel rods with increased proliferation resistance. Conduct of the HFEL at ORNL utilizes a currently unused building, personnel experienced in radioactive chemical operations, and support of an integrated research and development laboratory. Site relocation poses the problem of failure of another site to be equivalent to ORNL in terms of availability of a suitable building, equipment, and experienced personnel and would probably result in increased environmental impacts, particularly with construction of new facilities.

The staff has found that the proposed HFEL does not impose unacceptable levels of environmental impacts on man or the natural environment. In fact, compared with existing activities in the site area, the construction and operational impacts are virtually negligible. HFEL results to be obtained by the late 1980s are critical to the timely design and construction of a fabrication plant for proliferation-resistant nuclear reactor fuel rods. Therefore the staff concludes that the HFEL program should be approved as proposed.

REFERENCE FOR SECTION 9

1. J. W. Rytle, *Preliminary Draft Environmental Impact Statement for Hot Engineering Test Project at Oak Ridge National Laboratory*, ORNL/TM-6520, August 1978.

Appendix A
DESCRIPTION OF GEL-SPHERE-PAC FUEL PIN FABRICATION PROCESS

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Appendix A

DESCRIPTION OF GEL-SPHERE-PAC FUEL PIN FABRICATION PROCESS

The chemical flow sheet for gel-sphere-pac, which identifies all mass flows by number, is shown in Fig. A-1. The numbered mass streams are identified in Table A-1 according to several categories as indicated. The flow rates and composition of the significant mass flows are given in Tables A-2 through A-7. A brief description of the process and major operations follows.

A-1 RECEIVING AND STORAGE

Feed and makeup materials (stream 1, Fig. A-1) will be received at a process makeup area outside the hot cells on the second floor of the Thorium-Uranium Recycle Facility (TURF). Fissile materials will be received as nitrate solutions in batches of up to 10 kg of heavy metal (HM). The plutonium fuel is assumed to be from recovered PWR fuel and to have the same isotopic composition as the plutonium in the PWR fuel. Only ^{239}Pu and ^{241}Pu are considered to be fissile (approximately 70% by weight of total plutonium). The ^{233}U fuel is to be taken from the National Uranium Repository (Building 3019 at ORNL) and is approximately 92% fissile; it will contain 210 ppm of ^{232}U . The thorium to be used is almost pure ^{232}Th . A nitrate receiving station will be provided on the roof of cell D of TURF for receiving a transfer cask containing either ^{233}U or plutonium nitrate feed solution and for transferring the solution into cell D. The nitrate solution will be transferred through the cell roof by means of piping provided for that purpose. Receiving and storage of fissile nitrate solutions will be by means of a tank in cell D receiving up to 100 liters of solution (10 kg HM). The 100 liters of solution would correspond to a two-batch campaign.

A-2 VACUUM EVAPORATION AND FEED ADJUSTMENT SYSTEM

In this system, the feed (stream 3) in the form of nitrate solution is stripped of nearly all free acid by means of vacuum evaporation. Evaporation produces a feed solution of high concentration in fissile material (6 M HM after completion of evaporation), which is subsequently diluted with water to approximately 3 M HM (stream 7). To ensure formation of satisfactory microspheres, the evaporation and dilution are performed in two steps.

The liquid waste (stream 6, evaporator condensate) may contain up to approximately 0.001% of the HM (with entrainment) and up to approximately 0.01% of the ^{103}Ru and ^{106}Ru (uranium-plutonium case only) originally present in the feed solution (stream 1).

A-3 FEED SURGE AND METERING SYSTEM

The system consists of surge vessels and the feed metering equipment to control flow of the feed solution into the mixing system to produce microspheres of two different sizes (approximately 1200 and 300 μm) separately. The fissile feed material may be spiked (stream 9) with ^{60}Co (50 Ci of ^{60}Co per gram of total cobalt) to produce a dose rate of 5000 R/h at 0.3 m for 10 kg HM that is 25% fissile.

Fig. A-1. Chemical flow sheet for gel-sphere-pac, showing all mass flows.

A-4 BROTH PREPARATION

Broth preparation takes place in a tank in cell D also. The feed solution (stream 10) is mixed with equal volumes (stream 11) of a 3 M solution of urea and hexamethylenetetramine (hexa) at a rate of 0.6 kg HM per hour (1.4 mole ratio of urea or hexa to HM) for large microspheres. To avoid premature gelation, this mixture must be cooled and maintained at a temperature below -5°C until introduction to the gelation column.

Table A-1. Identification of mass streams in gel-sphere-pac flow sheet

[illegible]

Table A-1 (continued)

Main Product	Chemical input	Mass stream ^a			Scrap	Stream description
		Hot off-gas	Combustible off-gas	Liquid waste		
		67			66	Reject fuel pins
	68					Off-gas from fuel pin inspection
69						Wipes in
	70					Fuel pins
						Packaging material
71						To option 1 (microspheres to sphere-cal)
		72				Off-gas from waste scrap handling
	73					From option 1 (fuel pins from sphere-cal)
	74					Recovered coarse microspheres

^aNumbers identify different streams in Fig. A-1.

A-5 SPHERE FORMING

Sphere forming will occur in a gelation column in cell D. The cooled feed material is to be pumped through a pulsed sphere-forming nozzle into a cylindrical column of circulating hot (85°C) trichloroethylene (stream 14), triggering the gelation reaction and solidifying the spherical drops. Conversion of uranyl nitrate to ammonium diuranate (ADU) and of $\text{Pu}(\text{NO}_3)_4$ to $\text{Pu}(\text{OH})_4$ [or $\text{Th}(\text{NO}_3)_4$ to $\text{Th}(\text{OH})_4$ in the ^{233}U -thorium case] is assumed to be mostly complete. The formation of ADU and $\text{Pu}(\text{OH})_4$ is the result of interaction of HM nitrates with ammonia liberated from decomposition of hexamethylenetetramine. The presence of urea enhances decomposition of hexa and retards hydrolysis of uranium compounds.

An integral part of the sphere-forming process is the hot organic circulation system. In the gel-sphere-pac process, the hot organic fluid required in gelation of mixed broth is trichloroethylene (controlled at a temperature of approximately 85°C). The system also transports a small purge stream of degraded organic fluid (stream 16) to the organic waste disposal system after filtration. The major function of the organic waste disposal system is to provide the surge capacity for the purged organic waste stream and to prepare the waste for subsequent disposal. The trichloroethylene will be absorbed on vermiculite, encased in plastic, and disposed of by land burial.

A-6 SPHERE-WASHING SYSTEM

This system performs several functions, including (1) separation of gel microspheres from the accompanying hot organic fluid, which is returned to the hot organic circulation system, (2) washing of microspheres with aqueous 0.5 M NH_4OH solution to remove the bulk of the urea, undecomposed hexa, ammonium nitrate, formaldehyde, etc., and (3) transfer of washed microspheres to the sphere-drying system (stream 23) and washed liquor to the aqueous waste surge system (stream 22).

A-7 SPHERE-DRYING SYSTEM

The washed microspheres are dried in air at 70-80°C in this system, and the water vapor released is condensed and transported to the aqueous waste surge (stream 25). A surge capacity is provided for about a one-week supply of dry microspheres of two sizes (approximately 300 and 1200 μm).

The description thus far has included main product mass stream flows (Fig. A-1) from feed and makeup material at the start to sphere drying (mass flows 1, 3, 7, 10, 12, 19, 23) with only a small loss of material (see Table A-2).

Table A-2. Flow rates and radionuclear compositions (major radionuclides) of main product streams in gel-sphere-pac preparation process
Fuel type uranium-plutonium, 25% fissile contain, 10 kg HM per week, 160-day cooled. Stream numbers identified in Fig. A-1

Constituent	Feed to HFEL, stream 1 (also 3, 7, 10, 12, 19)	Washed microspheres, stream 23	Acceptable dry microspheres, stream 26	Debonded, microspheres, stream 37	Sintered product, stream 43	Recycled, microspheres, stream 74 ^a	Fissile microspheres, total, stream 46 (also 51, 54, 57)	Fertile fines, stream 47 ^a	Fertile blanket, stream 56 ^a	Product of homogeneity inspection, stream 59 (also 61)			Product of welding, stream 65			Product of fuel pin inspection, stream 69		
										Coarse	Fine	Blanket	Coarse	Fine	Blanket	Coarse	Fine	Blanket
Heavy metals																		
U (g/week)	6520	6520	6194	6188	6182	928.8	7111	2726	10,596	6183	2371	9214	6157	2360	9175	6079	2330	9058
(Ci/week)	0.03	0.03	0.0285	0.0285	0.0285	4.282(−3) ^b	0.0328	negl.	negl.	0.0285	negl.	negl.	0.0284	negl.	negl.	0.028	negl.	negl.
Pu (g/week)	3478	3478	3304	3301	3298	495.5	3794			3299			3285			3243		
(Ci/week)	4.7(4)	4.7(4)	4.468(4)	4.464(4)	4.46(4)	6.7(3)	5.13(4)			4.46(4)			4.442(4)			4.39(4)		
^{242,244} Cm (g/week)	2(−6)	2(−6)	1.9(−6)	1.9(−6)	1.898(−6)	2.85(−7)	2.18(−6)			1.898(−6)			1.89(−6)			1.87(−6)		
(Ci/week)	1.1	1.1	1.045	1.044	1.043	0.1567	1.2			1.043			1.039			1.026		
Fission products and others																		
⁹⁵ Zr (g/week)	0.027	0.027	0.02565	0.02562	2.56(−2)	3.846(−3)	2.94(−2)			2.56(−2)			2.55(−2)			2.52(−2)		
(Ci/week)	570	570	541.5	541.0	540.5	81.21	621.7			540.6			538.3			531.5		
⁹⁵ Nb (g/week)	0.01	0.01	0.0095	9.49(−3)	9.48(−3)	1.424(−3)	1.09(−2)			9.48(−3)			9.44(−3)			9.32(−3)		
(Ci/week)	392	392	372.4	372.0	371.6	55.83	427.4			371.7			370.1			365.4		
^{103,106} Ru (g/week)	0.272	0.272	0.2584	0.2581	0.2553	3.84(−2)	0.2937			0.2554			0.2543			0.251		
(Ci/week)	996	996	946.2	945.3	934.9	140.5	1075			935.1			931.2			919.3		
¹³⁴ Cs (g/week)	0.024	5(−4)	4.75(−4)	4.75(−4)	4.7(−4)	7.06(−5)	5.41(−4)			4.7(−4)			4.68(−4)			4.62(−4)		
(Ci/week)	30.4	0.6	0.57	0.569	0.563	8.46(−2)	0.648			0.563			0.561			0.554		
¹³⁷ Cs (g/week)	0.166	0.003	0.00285	2.85(−3)	2.82(−3)	4.24(−4)	3.24(−3)			2.82(−3)			2.81(−3)			2.77(−3)		
(Ci/week)	14.7	0.3	0.285	0.285	0.282	4.24(−2)	0.324			0.282			0.281			0.277		
¹⁴⁴ Ce (g/week)	0.016	0.016	0.0152	1.52(−2)	1.50(−2)	2.25(−3)	1.725(−2)			1.5(−2)			1.49(−2)			1.47(−2)		
(Ci/week)	50	50	47.5	47.45	46.93	7.051	53.98			46.94			46.74			46.15		
¹⁵⁴ Eu (g/week)	3.1(−3)	3.1(−3)	2.945(−3)	2.942(−3)	2.91(−3)	4.37(−4)	3.35(−3)			2.91(−3)			2.9(−3)			2.15(−3)		
(Ci/week)	0.8	0.8	0.76	0.759	0.751	0.113	0.864			0.751			0.748			0.738		
⁶⁰ Co (g/week)	1 ^c	1	0.95	0.949	0.948	0.142	1.09			0.948			0.944			0.932		
(Ci/week)	1141 ^c	1141	1084	1083	1082	162.6	1245			1082			1078			1064		

^a Added to the main product stream at this point.

^b 4.282(−3) means 4.282 X 10^{−3}, etc.

^c Added between streams 7 and 10.

Table A-3. Flow rates and radionuclear compositions (major radionuclides) of aqueous liquid wastes, combustible off-gas, and hot off-gas streams in gel-sphere-pac preparation process

Fuel type uranium-plutonium, 25% fissile content, 10 kg HM per week, 160-day-cooled.
Stream numbers identified in Fig. A-1

Constituent	Liquid wastes					Combustible off-gas		Hot off-gas
	Evaporator condensate, stream 6	Gel-sphere wash, stream 22	Sphere-drying condensate, stream 25	Spent acid scrubber, stream 34	Sintering condensate, stream 40	Debonding furnace, stream 33	Sintering furnace, stream 41	Waste and scrap handling, stream 72 ^a
Heavy metals								
U (g/week)	0.065	0.065		5.57		0.6194	6.188	1.304
(Ci/week)	3(-7) ^b	3(-7)		2.57(-5)		2.05(-6)	2.05(-5)	6(-6)
Pu (g/week)	0.035	0.035		2.974		0.3304	3.301	0.696
(Ci/week)	0.47	0.47		40.21		4.468	44.64	9.41
^{242,244} Cm (g/week)		2(-11)		1.71(-9)		1.9(-10)	1.9(-9)	4(-10)
(Ci/week)		1(-5)		9.4(-4)		1.045(-4)	1.044(-3)	2.2(-4)
Fission products and others								
⁹⁵ Zr (g/week)		3(-7)		2.3(-5)		2.565(-6)	2.562(-5)	5.4(-6)
(Ci/week)		5.7(-3)		0.4874		5.41(-2)	0.541	0.114
⁹⁵ Nb (g/week)		1(-7)		8.55(-6)		9.5(-7)	9.49(-6)	2(-6)
(Ci/week)		3.8(-3)		0.3352		3.774(-7)	0.372	7.84(-2)
^{103,106} Ru (g/week)	3(-5)	3(-6)	3(-5)	2.33(-4)	2.32(-3)	2.584(-5)	5.162(-4)	5.44(-5)
(Ci/week)	0.1	0.01	0.1	0.852	8.508	9.467(-7)	1.8908	0.1992
¹³⁴ Cs (g/week)		0.024		4.28(-7)	4.28(-6)	4.75(-8)	9.5(-7)	1(-7)
(Ci/week)		30.4		5.13(-4)	5.12(-3)	5.7(-5)	1.138(-3)	1.2(-4)
¹³⁷ Cs (g/week)		0.166		2.57(-6)	2.57(-5)	2.85(-7)	5.7(-6)	6(-7)
(Ci/week)		14.7		2.57(-4)	2.57(-3)	2.85(-5)	5.7(-4)	6(-5)
¹⁴⁴ Ce (g/week)		2(-7)		1.37(-5)	1.37(-4)	1.52(-6)	3.04(-5)	3.2(-6)
(Ci/week)		5(-4)		4.28(-2)	4.27(-1)	4.75(-3)	9.49(-2)	1(-2)
¹⁵⁴ Eu (g/week)		3(-8)		2.65(-6)	2.65(-6)	2.945(-7)	5.884(-6)	6.2(-7)
(Ci/week)		8(-6)		6.84(-4)	6.83(-3)	7.6(-5)	1.518(-3)	1.6(-4)
⁶⁰ Co (g/week)		1(-5)		8.55(-4)		9.5(-5)	9.49(-4)	2(-4)
(Ci/week)		0.01		0.9756		0.1084	1.083	0.2282

^aIt is assumed that an amount equal to 20% of stream 72 enters the cell ventilation system.

^b3(-7) means 3×10^{-7} , etc.

Table A-4. Flow rates and radionuclear compositions (major radionuclides) of scrap streams in gel-sphere-pac preparation process

Fuel type uranium-plutonium, 25% fissile content, 10 kg HM per week, 160-day-cooled.
Stream numbers identified in Fig. A-1

Constituent	Scrap dry microspheres, stream 30	Rejected fuel pins from homogeneity inspection, stream 58			Rejected fuel pins from welding, stream 64			Reject fuel pins from fuel pin inspection, stream 66		
		Coarse	Fine	Blanket	Coarse	Fine	Blanket	Coarse	Fine	Blanket
Heavy metals										
U (g/week)	326	927.3	355	1382	26.27	10.1	39.16	78.43	30.06	116.9
(Ci/week)	1.5(−3) ^a	4.27(−3)	negl.	negl.	1.21(−4)	negl.	negl.	3.62(−4)	negl.	negl.
Pu (g/week)	174	495			14.0			41.8		
(Ci/week)	2.35(3)	6.69(3)			189.6			565.8		
^{242,244} Cm (g/week)	1(−7)	2.85(−7)			8.07(−9)			2.41(−8)		
(Ci/week)	5.5(−2)	0.156			4.43(−3)			1.32(−2)		
Fission products and others										
⁹⁵ Zr (g/week)	1.35(−3)	3.84(−3)			1.09(−4)			3.25(−4)		
(Ci/week)	28.5	81.1			2.30			6.86		
⁹⁵ Nb (g/week)	5(−4)	1.42(−3)			4.03(−5)			1.2(−4)		
(Ci/week)	19.6	55.7			1.58			4.71		
^{103,106} Ru (g/week)	1.36(−2)	3.83(−2)			1.09(−3)			3.24(−3)		
(Ci/week)	49.8	140			3.97			11.8		
¹³⁴ Cs (g/week)	2.5(−5)	7.05(−5)			2.0(−6)			5.96(−6)		
(Ci/week)	3(−2)	8.44(−2)			2.39(−3)			7.14(−3)		
¹³⁷ Cs (g/week)	1.5(−4)	4.23(−4)			1.2(−5)			3.58(−5)		
(Ci/week)	1.5(−2)	4.23(−2)			1.2(−3)			3.58(−3)		
¹⁴⁴ Ce (g/week)	8(−4)	2.25(−3)			6.4(−5)			1.9(−4)		
(Ci/week)	2.5	7.04			0.2			0.595		
¹⁵⁴ Eu (g/week)	1.55(−4)	4.36(−4)			1.24(−5)			3.69(−5)		
(Ci/week)	4(−2)	0.113			3.19(−3)			9.53(−3)		
⁶⁰ Co (g/week)	5(−2)	0.142			4.03(−3)			1.2(−2)		
(Ci/week)	57	162			4.6			13.7		

^a 1.5(-3) means 1.5×10^{-3} , etc.

Table A-5. Flow rates and radionuclear compositions (major radionuclides) of main product streams in gel-sphere-pac preparation process
Fuel type ²³³U-thorium 25% fissile content, 10 kg HM per week, 15-year-cooled. Stream numbers identified in Fig. A-1

Constituent	Feed to HFEL, stream 1 (also, 3, 7, 10, 12, 19, 23)	Acceptable dry microspheres, stream 26	Debonded microspheres, stream 37	Sintered product, stream 43	Recycled microspheres, stream 74 ^a	Microspheres, total, stream 46 (also 51, 54, 57)	Fertile fines, stream 47 ^a	Fertile blanket, stream 56 ^a	Product of homogeneity inspection, stream 59 (also 61)			Product of welding, stream 65			Product of fuel pin inspection, stream 69		
									Coarse	Fine	Blanket	Coarse	Fine	Blanket	Coarse	Fine	Blanket
Heavy metals																	
Total U (g/week)	2710	2575	2572	2569	386	2955			2570			2559			2526		
(Ci/week)	36.9	35.1	35.06	35.03	5.26	40.3			35.04			34.89			34.45		
²³² U (g/week)	0.568	0.54	0.5395	0.539	0.081	0.62			0.539			0.537			0.53		
(Ci/week)	12.2	11.6	11.59	11.58	1.74	13.32			11.58			11.53			11.39		
²³³ U (g/week)	2483	2359	2357	2355	354	2709			2356			2346			2316		
(Ci/week)	23.5	22.3	22.28	22.26	3.34	25.6			22.27			22.17			21.89		
²³⁹ Pu (g/week)	0.049	0.047	0.047	0.047	7.06(−3) ^b	5.41(−2)			4.7(−2)			4.7(−2)			4.6(−2)		
(Ci/week)	3(−3)	2.85(−3)	2.85(−3)	2.85(−3)	4.28(−4)	3.28(−3)			2.85(−3)			2.84(−3)			2.8(−3)		
Total Th (g/week)	7290	6926	6919	6912	1038	7950	3101	12,058	6914	2697	10,486	6884	2685	10,441	6797	2651	10,308
(Ci/week)	2.4(−3)	2.28(−3)	2.28(−3)	2.28(−3)	3.43(−4)	2.62(−3)	7(−4)	2.73(−3)	2.28(−3)	6.1(−4)	2.37(−3)	2.27(−3)	6.07(−4)	2.36(−3)	2.24(−3)	6(−4)	2.33(−3)
²³² Th (g/week)	5(−7)	4.75(−7)	4.745(−7)	4.74(−7)	7.12(−8)	5.45(−7)			4.74(−7)			4.72(−7)			4.66(−7)		
(Ci/week)	4(−4)	3.8(−4)	3.8(−4)	3.8(−4)	5.71(−5)	4.37(−4)			3.8(−4)			3.78(−4)			3.74(−4)		
²³² Th (g/week)	7290	6926	6919	6912	1038	7950	3101	12,058	6914	2697	10,486	6884	2685	10,441	6797	2651	10,308
(Ci/week)	2(−3)	1.9(−3)	1.9(−3)	1.9(−3)	2.85(−4)	2.19(−3)	3.4(−4)	1.3(−3)	1.9(−3)	2.9(−4)	1.15(−3)	1.89(−3)	2.9(−4)	1.14(−3)	1.87(−3)	2.9(−4)	1.13(−3)
Other																	
⁶⁰ Co (g/week)	1.1 ^c	1.045	1.044	1.043	0.1667	1.2			1.043			1.039			1.026		
(Ci/week)	1211 ^c	1151	1150	1149	173	1322			1149			1144			1130		

^a Added to the main product stream at this point.

^b 7.06(−3) means 7.06 X 10^{−3}, etc.

^c Added between streams 7 and 10.

Table A-6. Flow rates and radionuclear compositions (major radionuclides) of liquid wastes, combustible off-gas, and hot off-gas streams in gel-sphere-pac preparation process

Fuel type ^{233}U -thorium, 25% fissile content, 10 kg HM per week, 15-year cooled.
Stream numbers identified in Fig. A-1

Constituent	Liquid wastes			Combustible off-gas		Hot off-gas	
	Evaporator condensate, stream 6	Gel-sphere wash, stream 22	Spent acid scrubber, stream 34	Debonding furnace, stream 33	Sintering furnace, stream 41	Waste and scrap handling, stream 72	Microsphere preparation, streams 4, 8, 13, 24
Heavy metals							
Total U (g/week) (Ci/week)	0.027 3.7(-4) ^a	0.027 3.7(-4)	2.32 0.032	0.2575 3.51(-3)	2.572 3.5(-2)	0.542 7.38(-3)	
^{232}U (g/week) (Ci/week)	6(-6) 1.2(-4)	6(-6) 1.2(-4)	4.86(-4) 1.04(-2)	5.4(-5) 1.16(-3)	5.4(-4) 1.16(-2)	1.14(-4) 2.44(-3)	
^{233}U (g/week) (Ci/week)	0.025 2.4(-4)	0.025 2.4(-4)	2.123 2.01(-2)	0.2359 2.23(-3)	2.357 2.23(-2)	0.497 4.47(-3)	
^{239}Pu (g/week) (Ci/week)	5(-7) 3(-8)	5(-7) 3(-8)	4.2(-5) 2.57(-6)	4.7(-6) 2.85(-7)	4.7(-5) 2.85(-6)	9.8(-6) 6(-7)	
Total Th (g/week) (Ci/week)	0.073 2(-8)	0.073 2(-8)	6.233 2.05(-6)	0.6926 2.28(-7)	6.919 2.28(-6)	4.49 1.17(-6)	
^{228}Th (g/week) (Ci/week)	5(-12) 4(-9)	5(-12) 4(-9)	4.28(-10) 3.42(-7)	4.75(-11) 3.8(-8)	4.745(-10) 3.8(-7)	1(-10) 8(-8)	
^{232}Th (g/week) (Ci/week)	0.073 2(-8)	0.073 2(-8)	6.233 1.71(-6)	0.6926 1.9(-7)	6.919 1.9(-6)	4.49 7.28(-7)	
Other							
^{60}Co (g/week) (Ci/week)		1(-5) 0.01	9.41(-4) 1.035	1.045(-4) 0.1151	1.044(-3) 1.15	2.2(-4) 0.242	
^{219}Rn (g/week) (Ci/week)				1.14(-19) 1.4(-9)	8.43(-19) 1.09(-8)		2.66(-19) 3.42(-9)
^{220}Rn (g/week) (Ci/week)				2.27(-9) 2.08	1.64(-8) 14.99		5.14(-9) 4.71
^{222}Rn (g/week) (Ci/week)				4.81(-14) 7.42(-9)	4.69(-14) 7.26(-9)		5.23(-15) 8.06(-10)

^a3.7(-4) means 3.7×10^{-4} , etc.

A-8 AQUEOUS WASTE SURGE SYSTEM

All aqueous waste streams are collected in this system for sampling and analysis before distribution to appropriate ORNL waste treatment subsystems, as governed by the nature of the contaminants and radioactivity levels.

A-9 ORNL WASTE SYSTEM

Waste streams generated in HFEL operations interface at this point with ORNL waste systems for ultimate disposal. This topic is discussed more fully in the main body of this report. Various process equipment includes, for example, filters, the ion exchange system, evaporators, the chemical precipitation and scavenging system, incinerator (or burner), etc. (Sect. 2.2.3.1).

A-10 DRIED MICROSPHERE INSPECTION

The dried microspheres are pneumatically transferred in air into a receiving hopper (stream 26). The amount of air is calculated by assuming an air flow of 100 standard liters per minute and 1 min to transfer 1 kg of material. The transfer air is vented to the hot-off-gas system (stream 28). The particles are fed by gravity through a weigher and then a passive sampler, which removes a 1/1000 sample and deposits the remainder of the batch in a transfer hopper. The sample is pneumatically transferred in air to a sample inspection station, where it is

Table A-7. Flow rates and radionuclear compositions (major radionuclides) of scrap streams in gel-sphere-pac preparation process

Fuel type ^{233}U -thorium, 25% fissile content, 10 kg HM per week, 15-year-cooled.
Stream numbers identified in Fig. A-1

Constituent	Scrap dry microspheres, stream 30	Rejected fuel pins from homogeneity inspection, stream 58			Rejected fuel pins from welding, stream 64			Rejected fuel pins from fuel pin inspection, stream 66		
		Coarse	Fine	Blanket	Coarse	Fine	Blanket	Coarse	Fine	Blanket
Heavy metals										
Total U (g/week)	135.5	385			10.92			32.59		
(Ci/week)	1.845	5.25			0.15			0.444		
²³² U (g/week)	0.0284	0.081			2.3(-3) ^a			6.84(-3)		
(Ci/week)	0.61	1.74			4.9(-2)			0.147		
²³³ U (g/week)	124.2	353			10.01			29.88		
(Ci/week)	1.175	3.34			9.5(-2)			0.2824		
²³⁹ Pu (g/week)	2.45(-3)	7.05(-3)			2(-4)			5.96(-4)		
(Ci/week)	1.5(-4)	4.275(-4)			1.21(-5)			3.62(-5)		
Total Th (g/week)	364.5	1037	404	1572	29.38	11.46	44.55	87.69	34.2	133
(Ci/week)	1.2(-4)	3.42(-4)	9.13(-5)	3.55(-4)	9.7(-6)	2.59(-6)	1.07(-5)	2.89(-5)	7.73(-6)	3.0(-5)
²³² Th (g/week)	2.5(-8)	7.11(-8)			2.01(-9)			6(-9)		
(Ci/week)	2(-5)	5.7(-5)			1.62(-6)			4.82(-5)		
²³² Th (g/week)	364.5	1037	404	1572	29.38	11.46	44.55	87.69	34.2	133
(Ci/week)	1(-4)	2.85(-4)	4.4(-5)	1.7(-4)	8.08(-6)	1.25(-6)	4.87(-6)	2.41(-5)	3.74(-6)	1.45(-5)
Other										
⁶⁰ Co (g/week)	5.5(-2)	0.1565			4.43(-3)			1.32(-2)		
(Ci/week)	00.55	172			4.00			14.50		

^a2.3(-3) means 2.3×10^{-3} , etc.

inspected for size and shape distribution and returned intact to the batch via pneumatic transfer. If acceptable, the batch is pneumatically transferred in air (stream 52) to a receiving hopper above the debonding furnace. If unacceptable, the batch is pneumatically transferred in air to waste and scrap handling. It was assumed that 5% of the batches are rejected at this stage (stream 30).

A-11 DEBONDING

The acceptable dried microspheres are pneumatically transferred by air to the debonding furnace, where the particles are debonded by heating for 30 min at 500°C in an atmosphere of argon plus 4 vol % hydrogen. It is assumed that in the incoming microspheres all the uranium is present as ammonium diuranate, $(\text{NH}_4)_2\text{U}_2\text{O}_7$; the plutonium is present as plutonium dioxide, PuO_2 ; and the thorium is present as thorium dioxide, ThO_2 . The transfer air is vented through sintered metal filters to the hot-off-gas system (stream 32). The flow rate of the argon-hydrogen mixture, 50 standard liters per minute, is assumed to be the same in the debonding and sintering furnaces. (It is likely that debonding and sintering will occur in the same furnace.) The decomposition reaction (debonding) is assumed to be

The off-gases, containing ammonia and water from the decomposition of ammonium diuranate and particulates, flow along with the argon and hydrogen to a nitric acid condenser scrubber, where 99% of the ammonia and water are deposited. It is assumed there are no decomposition products

from PuO_2 and ThO_2 . About 0.1% of the batch is assumed lost as particulates to the off-gas stream from the furnace to the scrubber, which removes 90%. The scrubber solution is assumed to be 2 M HNO_3 . The spent solution from the scrubber (stream 34) is sent to the aqueous waste surge. The remaining off-gases flow to the special combustible off-gas system (stream 33). In the ^{233}U -thorium case, radon is produced. It is assumed that 99% of the built-up radon and all that produced by decay during the 30 min of the process are evolved. The calcined microspheres are drained by gravity into a transfer hopper, from which they are pneumatically transferred in air (stream 37) to the sintering furnace.

All three processes, gel-sphere-pac, HTGR green fuel rods, and sphere-cal, have followed the same path up to this point. Following the debonding process, the microspheres in the sphere-cal process (option 1, see Appendix B) branch off (stream 71) for different operations, while those for gel-sphere-pac and HTGR green fuel rod processes continue on to the sintering process discussed next (stream 37).

A-12 SINTERING

The microspheres are sintered in a static bed under flowing argon containing 4 vol % hydrogen (50 standard liters per min). The amount of hydrogen required is five times the amount required to reduce all the UO_3 . The reduction reaction of UO_3 is assumed to be:

The assumed time for sintering is 4 hr.

In sintering uranium-plutonium fuel, it is assumed that 1% (0.5% as gases and 0.5% as particulates) of the more volatile fission products such as Ru, Cs, Ce, and Eu and 0.1% of the other radionuclides (as particulates) are released to the off-gas system. In sintering ^{233}U -thorium fuel, 99% of the built-up radon, 100% of the decay radon, and 0.1% of the other radionuclides (as particulates) are assumed released to the off-gas system.

These off-gases from the sintering furnace (stream 41) flow through a condenser, which removes 90% of the reaction water and 90% of the Ru, Cs, Ce, and Eu, to the combustible off-gas system. The heavy metals and fission products, except the radon, which is gaseous, are now assumed to be present only as particulates. The condensate (stream 40) is sent to aqueous waste surge. The transfer air for the incoming particles is vented (stream 42) to the hot-off-gas system.

A-13 SINTERED MICROSPHERE INSPECTION

The microspheres are pneumatically transferred in air to a sampler, which removes a 1/1000 sample that is analyzed for size and shape distribution, heavy-metal content, fissile isotopic content, and levels of impurities. All parts of the sample other than those used for the wet chemical analyses are returned to the batch. If acceptable, the batch is pneumatically transferred to surge (stream 46). If not, the batch is transferred to waste and scrap handling. The rejects of the sintered batches are expected to be small and, for the purposes of these mass flows, are neglected.

In addition to the primary stream from the sintering furnace, the sintered microsphere inspection station will receive microspheres recovered in waste and scrap handling from rejected fuel pins (stream 74).

A-14 SURGE, VOLUME DISPENSE

Acceptable sintered batches are pneumatically transferred (stream 46) to surge, where they are stored until required by sphere-pac loading. Fertile fines (stream 47) of either uranium or thorium as used in sphere-pac are pneumatically transferred to volume dispense. The transfer air is vented to the hot-off-gas system (stream 53). The coarse and fine microspheres are pneumatically transferred from surge to volume dispense, then by gravity to fuel pin loading. The HTGR green fuel rod fabrication process branches off at this point (stream 50; see Appendix C).

A-15 FUEL PIN LOADING

Fuel pin loading will take place in cell E of TURF. The sintered microspheres will be transferred through the air lock separating cells D and E. The two sizes of fissile microspheres (1200 and 300 μm) and the smaller (approximately 30 μm) fertile microspheres are blended and compacted in a fuel cladding tube by means of low-energy vibration. This process is known as sphere-pac. The necessary pin hardware (stream 55) and fertile blanket material (stream 56) will be loaded into the cladding prior to and following the fuel pin loading.

A-16 HOMOGENEITY INSPECTION

The unwelded loaded pins are sent to homogeneity inspection (stream 57), where the effectiveness of the sphere-pac loading is assessed by means of nondestructive passive or active gamma scanning. The acceptably loaded pins are sent to decontamination (stream 59). It is assumed that in a given pass, 15% of the fuel pins fail the homogeneity inspection. The unacceptable pins are sent to waste and scrap handling (stream 58), where the pin is disassembled and the microspheres are unloaded, screened, and returned to sintered microsphere inspection (stream 74). It is assumed that of the coarse microspheres in those pins, most are recovered for reuse for an overall loss of 1.5%. For reasons of simplicity, all the fertile fines and the hardware are sent to waste and scrap handling.

A-17 DECONTAMINATION, WELDING

The acceptable fuel pins are sent to decontamination (stream 59), where the fuel pin lip area is wiped to remove any debris and then sent to welding (stream 61), where the top end plug is welded. Any improperly welded pins are sent (stream 64) to waste and scrap handling, where they are disassembled and the coarse microspheres are recovered. It is assumed that 5% of the pins will be rejected by the welding operator due to obviously bad welds.

A-18 FUEL PIN INSPECTION

The apparently acceptably welded pins are sent to fuel pin inspection (stream 65), where they are x-rayed and leak-tested. About 1.5% of the pins are assumed to fail these tests and are sent to waste and scrap handling (stream 66), where they are disassembled; the coarse microspheres are recovered, and the fertile fines and hardware are sent to waste. The acceptable pins are prepared for shipment and are then removed from cell E through a roof hatch by means of a transfer cask that mates with the roof hatch to ensure containment of radioactive materials. Lastly, outside the hot cells the fuel pins will be transferred from the transfer cask to an approved shipping cask.

A-19 WASTE AND SCRAP HANDLING

Waste and scrap handling receives rejected dried microspheres and rejected fuel pins. The rejected fuel pins are disassembled. The microspheres are screened to remove the coarse from the fertile fines. The fines and the fuel pin hardware, along with the dried microspheres, are prepared for disposal either as retrievable scrap or by burial. The coarse microspheres are recycled back to sintered microsphere inspection for reuse (stream 74). It is assumed that 10% of the coarse microspheres sent to waste and scrap handling in rejected fuel pins are lost to the waste stream.

The waste and scrap handling is apt to be a dusty operation similar to those encountered in fresh fuel plant fabrication pellets. Based on assumptions used in previous studies,¹ it is assumed that 0.02% of the fuel material in the microsphere-forming line is lost as particulates to the hot-off-gas system and 0.004% is lost to the cell ventilation system. These losses are based on experience in large scale commercial fabrication of pellets from loose powders. As the losses from fabrication using microspheres are expected to be much less, the assumption of these losses is very conservative.

REFERENCE FOR APPENDIX A

1. W. S. Groenier et al., *Correlation of Radioactive Wastes Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing as Low as Practicable Guides - Fabrication of Light Water Reactor Fuels Containing Plutonium*, ORNL/TM-4904 (May 1973), pp. 20-21.

Appendix B
DESCRIPTION OF SPHERE-CAL FUEL PIN FABRICATION PROCESS

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Appendix B

DESCRIPTION OF SPHERE-CAL FUEL PIN FABRICATION PROCESS

The sphere-cal process is identical with the gel-sphere-pac process through the debonding step (see Fig. A-1, Appendix A). The processes then diverge. The chemical flow sheet for sphere-cal after this divergence (mass stream 71, Fig. A-1) is shown in Fig. B-1. The numbered mass streams in Fig. B-1 are identified in Table B-1. The flow rates and chemical compositions of the significant mass flows for the sphere-cal process are given in Tables B-2 through B-7. A brief description of the major operations unique to the sphere-cal process follows.

B-1 MICROSPHERE INSPECTION

The microspheres are received from debonding (stream 71, Figs. A-1 and B-1) in a receiving hopper. The transfer air is vented (stream 103) through a sintered metal filter to the hot-off-gas system. The batch is drained by gravity through a passive sampler, which removes a 1/1000 sample into a transfer hopper. If found acceptable, the main batch is pneumatically transferred in air to pellet pressing. If unacceptable, the batch is pneumatically transferred in air (stream 101) to waste and scrap handling. It is assumed that 0.5% of the batches are rejected.

B-2 PELLET PRESSING

A solid lubricant powder (a vegetable stearate — 1.2 wt % of the weight of the microspheres) is added to the microspheres (stream 106), and the mixture is blended to coat thoroughly the

Fig. B-1. Flow sheet for the sphere-cal process, showing all mass flows.

Table B-1. Identification of mass streams in sphere-cal flow sheet

Main Product	Mass stream ^a					Scrap	Stream description
	Chemical input	Hot off-gas	Combustible off-gas	Liquid waste	Burial grounds		
71		72					Debonded microspheres
	102					101	Off-gas from waste and scrap handling
		103					Reject microspheres
104							Transfer air in
	106						Transfer air out
	107					105	Microsphere feed to pellet press
		108					Reject green pellets
109							Die lubricant
	110						Transfer and purge air in
			111				Transfer and purge air out
				112			Green pellets
113							Argon—4% hydrogen
							Furnace off-gas
							Off-gas condensate
							Sintered pellets
115						114	Reject sintered pellets
117	118						Sintered pellets
						116	Grinding dust
							Ground pellets
120							Oversize pellets for regrinding
	121						Reject pellets
	122						Ground pellets
123							Fuel pin hardware
						124	Blanket fertile material
125							Loaded fuel pins
							Reject fuel pins
127	128				126		Acceptable loaded fuel pins
		129					Wipes
							Decontaminated fuel pins
							Argon, helium
131						130	Off-gas from welding
		133					Reject welded fuel pins
						132	Acceptable welded fuel pins
134							Reject fuel pins
	135						Off-gas from fuel pin inspection
	136						Fuel pins
	137						Packaging materials
							Recovered pellets
							Recycled pellets

^aNumbers identify different streams in Fig. B-1.

microspheres with lubricant. The coated microspheres are then dispensed into previously lubricated pellet molds. The microspheres are pressed in the mold to form green pellets. Any obviously bad pellets are diverted (stream 105) to waste and scrap handling. Apparently acceptable pellets are transferred to pellet sintering (stream 109). It is assumed that 0.5% of the green pellets are rejected and sent to waste and scrap handling.

B-3 PELLET SINTERING

The pellets are sintered in a static bed under flowing argon containing 4 vol % hydrogen. Pellet sintering is assumed to be similar to microsphere sintering in the gel-sphere-pac process (see Appendix A). The stearate added as a lubricant in the pressing step is assumed to decompose or distill out of the pellets during the sintering process and leave no residue. The sintered pellets (nominally about 5 mm in diameter) are removed from the furnace, cooled, and transferred to sintered pellet inspection (stream 113).

Table B-2. Flow rates and radionuclear compositions (major radionuclides) of main product streams in sphere-cal preparation process
Fuel type uranium-plutonium, 25% fissile content, 10 kg HM per week, 160-day-cooled. Stream numbers 1-74 identified in Fig. A-1, numbers 71, 72, and 101-137 in Fig. B-1

Constituent	Feed to HFEL, stream 1 (also, 3, 7, 10, 12, 19, 23, 26, 52)	Debonded microspheres, stream 71	Acceptable microspheres, stream 104	Acceptable pressed pellets, stream 109	Sintered pellets, stream 113	Acceptable pellets stream 115	Ground pellets, stream 117	Recovered pellets, stream 136 ^a	Acceptable pellets, stream 120 (also 123)	Fertile blanket stream 122 ^a	Product of homogeneity, inspection, stream 125 (also 127)		Product from welding, stream 131		Product from fuel pin inspection, stream 134	
											Fuel	Blanket	Fuel	Blanket	Fuel	Blanket
Heavy metals																
U (g/week) (Ci/week)	7216 0.024	7209 0.024	7173 0.024	7137 0.024	7130 0.024	6702 0.0226	6049 0.0204	401 1.35(−3) ^b	6449 0.0217	6956 negl.	6389 0.0215	6891 negl.	6090 0.0205	6568 negl.	6004 0.0202	6475 negl.
Pu (g/week) (Ci/week)	2782 3.762(4)	2779 3.758(4)	2765 3.739(4)	2751 3.72(4)	2748 3.72(4)	2583 3.5(4)	2331 3.16(4)	154 2091	2486 3.36(4)		2462 3.33(4)		2347 3.18(4)		2314 3.133(4)	
^{242,244} Cm (g/week) (Ci/week)	1.6(−6) 0.88	1.6(−6) 0.879	1.6(−6) 0.875	1.6(−6) 0.871	1.6(−6) 0.87	1.5(−6) 0.818	1.36(−6) 0.738	9(−8) 4.9(−2)	1.45(−6) 0.787		1.43(−6) 0.78		1.37(−6) 0.743		1.35(−6) 0.733	
Fission products and others																
⁹⁵ Zr (g/week) (Ci/week)	2.16(−2) 456	2.16(−2) 456	2.15(−2) 454	2.14(−2) 452	2.14(−2) 452	2.01(−2) 425	1.82(−2) 383	1.2(−3) 25.4	1.94(−2) 409		1.92(−2) 405		1.83(−2) 386		1.8(−2) 381	
⁹⁵ Nb (g/week) (Ci/week)	8(−3) 313.6	8(−3) 313.3	7.96(−3) 311.7	7.92(−3) 310	7.91(−3) 310	7.44(−3) 291.4	6.71(−3) 263	4.44(−4) 17.4	7.15(−3) 280		7.09(−3) 278		6.76(−3) 265		6.66(−3) 2.61	
^{103,106} Ru (g/week) (Ci/week)	0.2176 796.8	0.217 796	0.216 792	0.215 788	0.213 779	0.2 732	0.18 661	1.2(−2) 43.8	0.193 705		0.191 698		0.182 665		0.179 656	
¹³⁴ Cs (g/week) (Ci/week)	4(−4) 0.48	4(−4) 0.48	3.98(−4) 0.48	3.96(−4) 0.48	3.92(−4) 0.475	3.68(−4) 0.447	3.33(−4) 0.403	2.2(−5) 2.67(−2)	3.55(−4) 0.43		3.51(−4) 0.426		3.35(−4) 0.406		3.3(−4) 0.4	
¹³⁷ Cs (g/week) (Ci/week)	2.4(−3) 0.24	2.4(−3) 0.24	2.4(−3) 0.24	2.4(−3) 0.24	2.37(−3) 0.237	2.23(−3) 0.223	2.01(−3) 0.201	1.33(−4) 1.33(−2)	2.14(−3) 0.214		2.12(−3) 0.212		2.02(−3) 0.202		2(−3) 0.2	
¹⁴⁴ Ce (g/week) (Ci/week)	1.28(−2) 40	1.28(−2) 40	1.28(−2) 39.8	1.28(−2) 39.6	1.27(−2) 39.2	1.2(−2) 36.8	1.08(−2) 33.3	7.14(−4) 2.2	1.15(−2) 35.4		1.14(−2) 35.1		1.08(−2) 33.5		1.07(−2) 33	
¹⁵⁴ Eu (g/week) (Ci/week)	2.48(−3) 0.64	2.48(−3) 0.64	2.47(−3) 0.64	2.46(−3) 0.64	2.43(−3) 0.63	2.28(−3) 0.592	2.06(−3) 0.534	1.37(−4) 3.54(−2)	2.2(−3) 0.57		2.18(−3) 0.565		2.08(−3) 0.54		2.05(−3) 0.53	
⁶⁰ Co (g/week) (Ci/week)	0.8 912.8	0.8 911.9	0.8 907.3	0.8 903	0.8 902	0.752 848	0.68 765	4.5(−2) 50.7	0.72 816		0.717 808		0.683 770		0.67 760	

^a Added to the main product stream at this point.

^b 1.35(-3) means 1.35 X 10⁻³, etc.

Table B-3. Flow rates and radionuclear compositions (major radionuclides) of liquid wastes, combustible off-gas, and hot off-gas streams in sphere-cal preparation process

Fuel type uranium-plutonium, 25% fissile content, 10 kg HM per week, 160-day-cooled.
Stream numbers 1-74 identified in Fig. A-1, numbers 71, 72, and 101-137 in Fig. B-1

Constituent	Liquid wastes					Combustible off-gas		Hot off-gas
	Evaporator condensate, stream 6	Gel-sphere wash, stream 22	Sphere drying condensate, stream 25	Spent acid scrubber, stream 34	Sintering condensate, stream 112	Debonding furnace, stream 33	Sintering furnace, stream 111	Waste and scrap handling, stream 72 ^a
Heavy metals								
U (g/week)	7.2(-2) ^b	7.2(-2)		0.494		0.7210	7.137	1.443
(Ci/week)	2.4(-7)	2.4(-7)		2.16(-5)		2.4(-6)	2.4(-5)	4.8(-6)
Pu (g/week)	2.8(-2)	2.8(-2)		2.5		0.2782	2.751	0.556
(Ci/week)	0.37	0.37		33.86		3.762	37.2	7.524
^{242,244} Cm (g/week)		1.6(-11)		1.44(-9)		1.6(-10)	1.6(-9)	3.2(-10)
(Ci/week)		8.8(-6)		7.92(-4)		8.8(-5)	8.71(-4)	1.76(-4)
Fission products and others								
⁹⁵ Zr (g/week)		2(-7)		1.94(-5)		2.16(-6)	2.14(-5)	4.32(-6)
(Ci/week)		4.5(-3)		0.4104		4.56(-2)	0.452	9.12(-2)
⁹⁵ Nb (g/week)		8(-8)		7.2(-6)		8(-7)	7.92(-6)	1.6(-6)
(Ci/week)		3.1(-3)		0.282		3.136(-2)	0.31	6.27(-2)
^{103,106} Ru (g/week)	2.2(-5)	2.2(-6)	2.2(-5)	1.96(-4)	1.94(-3)	2.176(-5)	4.3(-4)	4.35(-5)
(Ci/week)	8(-2)	8(-3)	8(-2)	0.717	7.09	7.97(-2)	1.576	0.16
¹³⁴ Cs (g/week)		4(-9)		3.6(-7)	3.56(-6)	4(-8)	7.92(-7)	8(-8)
(Ci/week)		4.8(-6)		4.32(-4)	4.32(-3)	4.8(-5)	9.6(-4)	9.6(-5)
¹³⁷ Cs (g/week)		2.4(-8)		2.16(-6)	2.16(-5)	2.4(-7)	4.8(-6)	4.8(-7)
(Ci/week)		2.4(-6)		2.16(-4)	2.16(-3)	2.4(-5)	4.8(-4)	4.8(-5)
¹⁴⁴ Ce (g/week)		1.3(-7)		1.15(-5)	1.15(-4)	1.28(-6)	2.56(-5)	2.56(-6)
(Ci/week)		4(-4)		3.6(-2)	0.356	4(-3)	7.92(-2)	8(-3)
¹⁵⁴ Eu (g/week)		2.5(-8)		2.23(-6)	2.21(-5)	2.48(-7)	4.92(-6)	4.98(-7)
(Ci/week)		6.4(-6)		5.76(-4)	5.76(-3)	6.4(-5)	1.28(-3)	1.28(-4)
⁶⁰ Co (g/week)		8(-6)		7.2(-4)		8(-5)	8(-4)	1.6(-4)
(Ci/week)		9(-3)		0.822		9.128(-2)	0.903	0.183

^aIt is assumed that an amount equal to 20% of stream 72 enters the cell ventilation system.

^b7.2(-2) means 7.2×10^{-2} , etc.

Table B-4. Flow rates and radionuclear compositions (major radionuclides) of scrap streams in sphere-cal preparation process
 Fuel type uranium-plutonium, 25% fissile content, 10 kg HM per week, 160-day-cooled. Stream numbers identified in Fig. B-1

Constituent	Rejected microspheres, stream 101	Rejected green pellets, stream 105	Samples and rejected sintered pellets, stream 114	Grinding dust, stream 116	Rejected fuel pins from homogeneity inspection, stream 124		Rejected fuel pins from welding, stream 130		Rejected pins from fuel pin inspection, stream 132	
					Fuel	Blanket	Fuel	Blanket	Fuel	Blanket
Heavy metals										
U (g/week)	36.05	35.87	428	653.5	60.5	65.2	299.5	323	85.35	92
(Ci/week)	1.2(−4) ^a	1.2(−4)	1.44(−3)	2.2(−3)	2.04(−4)	negl.	1(−3)	negl.	2.87(−4)	negl.
Pu (g/week)	13.9	13.83	165	252	23.3		115		32.9	
(Ci/week)	188	187	2.33(3)	3.41(3)	315		1.562(3)		445	
^{242,244} Cm (g/week)	8(−9)	8(−9)	9.6(−8)	1.47(−7)	1.36(−8)		6.72(−8)		1.92(−8)	
(Ci/week)	4.4(−3)	4.4(−3)	5.22(−2)	7.97(−2)	7.38(−3)		3.65(−2)		1.04(−2)	
Fission product and others										
⁹⁵ Zr (g/week)	1.08(−4)	1.1(−4)	1.28(−3)	1.96(−3)	1.81(−4)		9(−4)		2.56(−4)	
(Ci/week)	2.28	2.27	27.1	41.4	3.83		19		5.41	
⁹⁵ Nb (g/week)	4(−5)	3.98(−5)	4.75(−4)	7.25(−4)	6.71(−5)		3.32(−4)		9.47(−5)	
(Ci/week)	1.57	1.56	18.6	28.4	2.63		13.02		3.71	
^{103,106} Ru (g/week)	1.09(−3)	1.1(−3)	1.28(−2)	1.95(−2)	1.81(−3)		8.95(−3)		2.55(−3)	
(Ci/week)	3.98	3.96	46.7	71.4	6.61		32.72		9.32	
¹³⁴ Cs (g/week)	2(−6)	2(−6)	2.35(−5)	3.59(−5)	3.32(−6)		1.65(−5)		4.69(−6)	
(Ci/week)	2.4(−3)	2.4(−3)	2.85(−2)	4.35(−2)	4.03(−3)		2(−2)		5.69(−3)	
¹³⁷ Cs (g/week)	1.2(−5)	1.2(−5)	1.42(−4)	2.17(−4)	2.01(−5)		1(−4)		2.84(−5)	
(Ci/week)	1.2(−3)	1.2(−3)	1.42(−2)	2.17(−2)	2.01(−3)		1(−2)		2.84(−3)	
¹⁴⁴ Ce (g/week)	6.4(−5)	6.4(−5)	7.62(−4)	1.16(−3)	1.08(−4)		5.33(−4)		1.52(−4)	
(Ci/week)	0.2	0.2	2.35	3.59	0.332		1.65		0.469	
¹⁵⁴ Eu (g/week)	1.24(−5)	1.24(−5)	1.46(−4)	2.23(−4)	2.06(−5)		1.02(−4)		2.91(−5)	
(Ci/week)	3.2(−3)	3.2(−3)	3.78(−2)	5.77(−2)	5.34(−3)		2.65(−2)		7.54(−3)	
⁶⁰ Co (g/week)	4(−3)	4(−3)	4.8(−2)	7.33(−2)	6.78(−3)		3.36(−2)		9.6(−2)	
(Ci/week)	4.56	4.54	54.1	82.7	7.65		37.9		10.8	

^a1.2(-4) means 1.2×10^{-4} , etc.

Table B-5. Flow rates and radionuclear compositions (major radionuclides) of main product streams in sphere-cal preparation process
Fuel type ²³³U-thorium, 10 kg HM per week, 15-year-cooled. Stream numbers 1-74 identified in Fig. A-1, numbers 71, 72, and 101-137 in Fig. B-1

Constituent		Feed to HFEL, stream 1 (also 3, 7, 10, 12, 19, 23, 26)	Debonded microspheres, stream 71	Acceptable microspheres, stream 104	Acceptable pressed pellets, stream 109	Sintered pellets, stream 113	Acceptable pellets, stream 115	Ground pellets, stream 117	Recovered pellets, stream 136 ^a	Acceptable pellets, stream 120 (also 123)	Fertile blanket pellets stream 122 ^a	Product of homogeneity inspection, stream 125 (also 127)		Product from welding, stream 131		Product from fuel pin inspection, stream 134	
												Fuel	Blanket	Fuel	Blanket	Fuel	Blanket
Heavy metals																	
Total	U (g/week)	2168	2166	2155	2144	2142	2013	1817	120.4	1938		1919		1829		1804	
	(Ci/week)	29.5	29.5	29.35	29.2	29.2	27.4	24.8	1.64	26.4		26.2		24.9		24.6	
²³² U	(g/week)	0.454	0.454	0.452	0.45	0.45	0.423	0.382	2.53(−2)	0.407		0.403		0.38		0.38	
	(Ci/week)	9.76	9.75	9.7	9.65	9.64	9.06	8.18	0.542	8.72		8.64		8.23		8.12	
²³³ U	(g/week)	1986	1984	1974	1964	1962	1844	1664	110	1775		1758		1676		1652	
	(Ci/week)	18.8	18.8	18.7	18.6	18.58	17.5	15.76	1.04	16.8		16.65		15.9		15.65	
²³⁹ Pu	(g/week)	0.039	0.039	0.039	0.039	0.039	0.037	0.033	2.2(−3)	0.035		0.035		0.033		0.033	
	(Ci/week)	2.4(−3) ^b	2.4(−3)	2.4(−3)	2.4(−3)	2.4(−3)	2.28(−3)	2.04(−3)	1.35(−4)	2.17(−3)		2.16(−3)		2.06(−3)		2.02(−3)	
Total	Th (g/week)	7832	7824	7785	7746	7738	7274	6565	435	6999	6946	6934	6881	6609	6559	6516	6466
	(Ci/week)	2.47(−3)	2.47(−3)	2.46(−3)	2.45(−3)	2.45(−3)	2.3(−3)	2.00(−3)	1.35(−4)	2.22(−3)	negl.	2.2(−3)	negl.	2.06(−3)	negl.	2.06(−3)	negl.
²²⁸ Th	(g/week)	4(−7)	4(−7)	3.97(−7)	3.96(−7)	3.96(−7)	3.72(−7)	3.36(−7)	2.23(−8)	3.58(−7)		3.55(−7)		3.38(−7)		3.33(−7)	
	(Ci/week)	3.2(−4)	3.2(−4)	3.18(−4)	3.16(−4)	3.16(−4)	2.97(−4)	2.68(−4)	1.78(−5)	2.86(−4)		2.83(−4)		2.7(−4)		2.66(−4)	
²³² Th	(g/week)	7832	7824	7785	7746	7739	7275	6565	435	6999	6946	6934	6881	6609	6559	6516	6466
	(Ci/week)	2.15(−3)	2.15(−3)	2.14(−3)	2.13(−3)	2.13(−3)	2(−3)	1.81(−3)	1.2(−4)	1.93(−3)	negl.	1.91(−3)	negl.	1.82(−3)	negl.	1.79(−3)	negl.
Other																	
⁶⁰ Co	(g/week)	0.88	0.88	0.876	0.872	0.872	0.82	0.74	4.9(−2)	0.79		0.781		0.745		0.732	
	(Ci/week)	969	968	963	959	958	903	812	53.8	866		859		818		806	

^a Added to the main product stream at this point.

^b 2.4(-3) means 2.4 X 10⁻³, etc.

Table B-6. Flow rates and radionuclear compositions (major radionuclides) of liquid wastes, combustible off-gas, and hot off-gas streams in sphere-cal preparation process

Fuel type ^{233}U -thorium, 10 kg HM per week, 15-year-cooled.
Stream numbers 1-74 identified in Fig A-1, numbers 71, 72, and 101-137 in Fig. B-1

Constituent	Liquid wastes			Combustible off-gas		Hot off-gas	
	Evaporator condensate, stream 6	Sphere wash, stream 22	Spent acid scrubber, stream 34	Debonding furnace, stream 33	Sintering furnace, stream 111	Waste and scrap handling, stream 72	Microsphere preparation, stream 4, 8, 13, 24
Heavy metals							
Total U (g/week) (Ci/week)	2.2(-2) ^a 3(-4)	2.2(-2) 3(-4)	1.951 2.66(-2)	0.2168 2.95(-3)	2.144 2.92(-2)	0.4336 5.9(-3)	
^{232}U (g/week) (Ci/week)	4.5(-6) 1(-4)	4.5(-6) 1(-4)	4.1(-4) 8.8(-3)	4.54(-5) 9.76(-4)	4.5(-4) 9.65(-3)	9.08(-5) 1.95(-3)	
^{233}U (g/week) (Ci/week)	2(-2) 2(-4)	2(-2) 2(-4)	1.79 1.7(-2)	0.1986 1.88(-3)	1.964 1.9(-2)	0.3972 3.76(-3)	
^{239}Pu (g/week) (Ci/week)	4(-7) 2.4(-8)	4(-7) 2.4(-8)	3.5(-5) 2.16(-6)	3.9(-6) 2.4(-7)	3.9(-5) 2.4(-6)	7.8(-6) 4.8(-7)	
Total Th (g/week) (Ci/week)	7.8(-2) 2.5(-8)	7.8(-2) 2.5(-8)	7.05 2.22(-8)	0.783 2.47(-7)	7.746 2.45(-8)	1.57 4.94(-7)	
^{228}Th (g/week) (Ci/week)	4(-12) 3.2(-9)	4(-12) 3.2(-9)	3.6(-10) 2.9(-7)	4(-11) 3.2(-8)	3.96(-10) 3.16(-7)	8(-11) 6.4(-8)	
^{232}Th (g/week) (Ci/week)	7.8(-2) 2.1(-8)	7.8(-2) 2.1(-8)	7.05 1.94(-6)	0.783 2.15(-7)	7.746 2.13(-6)	1.57 4.3(-7)	
Other							
^{60}Co (g/week) (Ci/week)		9(-6) 1(-2)	7.92(-4) 0.872	8.8(-5) 9.69(-2)	8.72(-4) 0.961	1.76(-4) 0.194	
^{219}Rn (g/week) (Ci/week)				9.6(-20) 1.18(-9)	7.03(-19) 9.09(-9)		2.13(-19) 2.74(-9)
^{220}Rn (g/week) (Ci/week)				1.91(-9) 1.75	1.37(-8) 12.5		4.1(-9) 3.77
^{222}Rn (g/week) (Ci/week)				4(-14) 6.25(-9)	3.91(-14) 6.05(-9)		4.18(-15) 6.45(-10)

^a 2.2(-2) means 2.2×10^{-2} , etc.

B-4 SINTERED PELLET INSPECTION

Some pellets from each batch (assumed 1%) are diverted as samples, which undergo chemical, isotopic, density, and microstructural analyses. Those batches that do not meet the microstructural requirements and can be made to do so by further sintering are recycled (stream 137) through the pellet sintering step. Those batches (approximately 5%) that do not meet chemical and isotopic specifications are transferred to waste and scrap handling (stream 114). The remaining 95% of the pellets that pass inspection are transferred to grinding (stream 115).

B-5 GRINDING

Pellets requiring grinding are fed into the grinder and ground to the proper diameter. The grinding is assumed to be dry diamond-wheel grinding. The grinding dust (assumed 9.75% dry weight) is collected in a can for ultimate delivery to waste and scrap handling (stream 116). The ground pellets are transferred to final pellet inspection (stream 117).

B-6 FINAL PELLET INSPECTION

All pellets are rechecked for proper diameters. Improperly sized pellets are sent back to grinding (stream 118). Properly sized pellets are forwarded to fuel pin loading (stream 120).

Table B.7. Flow rates and radionuclear compositions (major radionuclides) of scrap streams in sphere-cel preparation process

Fuel type ^{233}U -thorium, 10 kg HM per week, 15-year-cooled. Stream numbers identified in Fig. B-1

Constituent	Rejected microspheres, stream 101	Rejected green pellets, stream 105	Rejected sintered pellets, stream 114	Grinding dust, stream 116	Rejected fuel pins from homogeneity inspection, stream 124		Rejected fuel pins from welding, stream 130		Rejected pins from fuel pin inspection, stream 132	
					Fuel	Blanket	Fuel	Blanket	Fuel	Blanket
Heavy metals										
Total U (g/week)	10.83	10.78	128.5	196.3	18.16		90		26.64	
	(Ci/week)	0.1475	0.1468	1.752	2.68	0.25	1.23		0.35	
²³² U (g/week)	2.27(-3) ^a	2.26(-3)	0.027	0.041	3.8(-3)		0.019		5.4(-3)	
	(Ci/week)	4.9(-2)	4.85(-2)	0.578	0.884	8.2(-2)	0.405		0.115	
²³³ U (g/week)	9.92	9.87	118	180	16.6		82.4		23.5	
	(Ci/week)	9.4(-2)	9.35(-2)	1.115	1.7	0.158	0.78		0.222	
²³⁹ Pu (g/week)	1.95(-4)	1.95(-4)	2.34(-3)	3.6(-3)	3.3(-4)		1.64(-3)		4.7(-4)	
	(Ci/week)	1.2(-5)	1.2(-5)	1.44(-4)	2.2(-4)	2.03(-5)	1.01(-4)		2.9(-5)	
Total Th (g/week)	39.12	33.9	464	709	65.6	65	325	322.5	92.6	92.3
	(Ci/week)	1.24(-5)	1.23(-5)	1.47(-4)	2.25(-4)	2.08(-5)	negl.	1.03(-4)	negl.	2.93(-5)
²²⁸ Th (g/week)	2(-9)	1.99(-9)	2.38(-8)	3.63(-8)	3.36(-9)		1.65(-8)		4.74(-9)	
	(Ci/week)	1.6(-6)	1.59(-6)	1.9(-5)	2.9(-5)	2.68(-6)	1.33(-5)		3.78(-6)	
²³² Th (g/week)	39.12	38.9	464	709	65.6	65	325	322.5	92.6	92.3
	(Ci/week)	1.08(-5)	1.07(-5)	1.28(-4)	1.95(-4)	1.8(-5)	negl.	8.95(-5)	negl.	2.55(-5)
Other										
⁶⁰ Co (g/week)	4.4(-3)	4.38(-3)	5.23(-2)	8(-2)	7.39(-3)		3.65(-2)		1.08(-2)	
	(Ci/week)	4.85	4.82	57.6	88	8.14	40.3		11.9	

^a2.27(-3) means 2.27×10^{-3} , etc.

B-7 FUEL PIN LOADING

The pellets are loaded into fuel pins along with fertile blanket pellets (stream 122) and other fuel pin hardware (stream 121). The loaded pins are sent to homogeneity inspection (stream 123), where the effectiveness of the loading is assessed by densitometry. The unacceptable pins (assumed 1%) are sent to waste and scrap handling (stream 124).

B-8 WASTE AND SCRAP HANDLING

Waste and scrap handling receives rejected dried microspheres, rejected pellets, loose grinding powder, and rejected fuel pins. The rejected fuel pins are disassembled, the pellets removed, inspected, and, if acceptable, sent back to final pellet inspection. The fertile pellets, the fuel pin hardware, the dried microspheres, the rejected pellets, and loose grinding powders are prepared for disposal as either retrievable scrap or by burial.

Assumptions concerning losses of fuel material in the waste and scrap handling system as particulates to the hot off-gas system and to the cell ventilation system are the same as in the gel-sphere-pac process (Appendix A-19).

Differences in the detailed processing functional order are expected to reduce somewhat the rejected components at the latter steps (homogeneity inspection, decontamination, welding, fuel pin inspection, and packing and shipping) for the sphere-cal process. This would reduce the amount of scrap material processed and lower the resulting source term. However, in these calculations the scrap production rates are considered to be equivalent to the gel-sphere-pac process thus increasing somewhat the degree of conservatism.

Appendix C
DESCRIPTION OF HTGR GREEN FUEL ROD FABRICATION PROCESS

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Appendix C

DESCRIPTION OF HTGR GREEN FUEL ROD FABRICATION PROCESS

The process that produces HTGR green fuel rods is identical with the gel-sphere-pac process through the microsphere sintering step (see Fig. A-1, Appendix A). The sintered microspheres are inspected, collected in surge, and pneumatically transferred in air (stream 50, Fig. A-1) to a receiving and feed hopper above the coating furnace. The chemical flow sheet for the HTGR green fuel rod process from this point on is shown in Fig. C-1. The numbered mass streams in Fig. C-1 are identified in Table C-1. The mass flow rates and radiochemical compositions of the numbered streams for the HTGR green fuel rod process are given in Tables C-2 through C-7. A brief description of the coating furnace and associated off-gas handling system and of the green rod molding procedure follows.

C-1 COATING FURNACE AND RELATED EQUIPMENT

The batch (about 0.5 kg of heavy metal) is drained by gravity (stream 50, Figs. A-1 and C-1) from the receiving and feed hopper above the coating furnace into the graphite furnace. Two types of

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Fig. C-1. Chemical flow sheet for HTGR fuel rod molding, showing all mass flows.

Table C-1. Identification of mass streams in HTGR fuel rod fabrication flow sheet

Main Product	Chemical input	Hot off-gas	Mass stream			Scrap	Stream description
			Combustible off-gas	Liquid waste	Burial grounds		
50		72					Sintered microspheres
202							Off-gas from waste and scrap handling
203							Coated fuel particles
204							Coated fuel particles
			205				Coated fuel particles
			206				Furnace off-gas
			208		207		Furnace off-gas from perchloroethylene scrubber
				209			Spent perchloroethylene
							Scrubbed furnace off-gas
							Spent caustic scrubber medium
						210	Reject fuel particles
						211	Reject fuel particles
						212	Coated fuel particle samples
						213	Reject fuel particles
215	214						Process gases
216							Coated fuel particles
							Green fuel rods
						217	Reject fuel rods
						218	Matrix scrap
	219						Perchloroethylene in
	220						Caustic solution in
	221						Fertile and shim particles in
	222						Matrix slugs in

carbon coatings, the low-density buffer and the high-density inner low-temperature isotropic, are applied to the microspheres by cracking of acetylene or propylene diluted with some helium introduced in an argon fluidizing gas stream (stream 214) at temperatures around 1300°C. The furnace is cooled and the bed unloaded. The charge is first drained through a scalping screen to remove any agglomerates. The screened particles are fed to a transfer hopper and pneumatically transferred to another receiving hopper. From here they are gravity-fed to a precision weigh hopper, a sampler, and another transfer hopper. The sampler removes a 1/1000 sample, which is sent to sample inspection. If the results indicate the batch is acceptable, it is transferred back to the furnace for further coating. It is first given a coating of silicon carbide by decomposition of methyltrichlorosilane in hydrogen at 1550°C. (The hydrogen serves as the fluidizing gas.) The sampling cycle is repeated, and acceptable silicon carbide-coated batches are given another high-density outer low-temperature isotropic carbon coating. The product is unloaded as before, screened, weighed, and sampled. If acceptable, it is pneumatically transferred to storage. It is assumed that 0.1% of the batch is carried over in the off-gas (stream 205) in applying the four coatings. It is also assumed that 0.1% of the batch will stick during each of the four steps in coating for a total of 0.4% lost (stream 210), 0.1% of the batch is lost as agglomerates in each of the four coating steps for a total of 0.4% lost (stream 211), and 2% of the batches will be rejected in each of the four steps in the coating for a total of 8% lost (stream 213). Unacceptable batches are also sent to waste and scrap handling.

C-2 GREEN ROD MOLDING

On a very intermittent basis, green fuel rods are molded from the coated fuel material. The operation is carried out manually, involves very small quantities of material, and has virtually no releases.

Table C-2. Flow rates and radionuclear compositions (major radionuclides) of main product streams in HTGR green fuel rod fabrication process
Fuel type uranium, plutonium, 25% fissile content, 10 kg HM per week, 160-day-cooled.
Stream numbers 1-74 identified in Fig. A-1, numbers 50, 72, and 202-222 in Fig. C-1

Constituent	Feed to HFEL, stream 1 (also 3, 7, 10, 12, 19)	Washed microspheres, stream 23	Acceptable dry microspheres, stream 26	Debonded microspheres, stream 37	Sintered product, stream 43 (also 43, 50)	Coated fuel particles, stream 202	Coated fuel particles, stream 203	Coated fuel particles, stream 204
Heavy metals								
U (g/week) (Ci/week)	6520 0.03	6520 0.03	6194 0.0285	6188 0.0285	6182 0.0285	6151 0.0284	6126 0.0282	5632 2.6(-2) ^a
Pu (g/week) (Ci/week)	3478 4.7(4)	3478 4.7(4)	3304 4.468(4)	3301 4.464(4)	3298 4.46(4)	3282 4.438(4)	3268 4.42(4)	3004 4.06(4)
^{242,244} Cm (g/week) (Ci/week)	2(-6) 1.1	2(-6) 1.1	1.9(-6) 1.045	1.9(-6) 1.044	1.898(-6) 1.043	1.889(-6) 1.038	1.881(-6) 1.034	1.73(-6) 0.95
Fission products and others								
⁹⁵ Zr (g/week) (Ci/week)	0.027 570	0.027 570	0.02565 541.5	0.02565 541	2.56(-2) 540.5	2.55(-2) 537.8	2.54(-2) 535.6	2.33(-2) 492.4
⁹⁵ Nb (g/week) (Ci/week)	1(-2) 392	1(-2) 392	9.5(-3) 372.4	9.49(-3) 372	9.48(-3) 371.6	9.43(-3) 369.7	9.34(-3) 368.3	8.64(-3) 338.5
^{103,106} Ru (g/week) (Ci/week)	0.272 996	0.272 996	0.2584 946.2	0.2581 945.3	0.2553 934.9	0.2539 930.2	0.2529 926.5	0.223 851.7
¹³⁴ Cs (g/week) (Ci/week)	2.4(-2) 30.4	5(-4) 0.6	4.75(-4) 0.57	4.75(-4) 0.569	4.7(-4) 0.563	4.68(-4) 0.56	4.66(-4) 0.558	4.28(-4) 0.513
¹³⁷ Cs (g/week) (Ci/week)	1.66(-1) 14.7	3(-3) 0.3	2.85(-3) 0.285	2.85(-3) 0.285	2.82(-3) 0.282	2.81(-3) 0.281	2.79(-3) 0.279	2.57(-3) 0.257
¹⁴⁴ Ce (g/week) (Ci/week)	1.6(-2) 50	1.6(-2) 50	1.52(-2) 47.5	1.52(-2) 47.45	1.5(-2) 46.93	1.49(-2) 46.69	1.49(-2) 46.51	1.37(-2) 42.8
¹⁵⁴ Eu (g/week) (Ci/week)	3.1(-3) 0.8	3.1(-3) 0.8	2.945(-3) 0.76	2.942(-3) 0.759	2.91(-3) 0.751	2.9(-3) 0.747	2.88(-3) 0.744	2.65(-3) 0.684
⁶⁰ Co (g/week) (Ci/week)	1 ^b 1141 ^b	1 1141	0.95 1084	0.949 1083	0.948 1082	0.943 1077	0.939 1072	0.864 985.7

^a2.6(-2) means 2.6 X 10⁻², etc.

^bAdded between streams 7 and 10.

Table C-3. Flow rates and radionuclear compositions (major radionuclides) of liquid wastes, combustible off-gas, hot off-gas, and organic wastes in HTGR green fuel rod fabrication process

Fuel type uranium-plutonium, 25% fissile content, 10 kg HM per week, 160-day-cooled. Stream numbers 1-74 identified in Fig. A-1, numbers 50, 72, and 202-222 in Fig. C-1

Constituent	Liquid wastes						Combustible off-gas			Hot off-gas	Organic wastes
	Evaporator condensate, stream 6	Gel-sphere wash, stream 22	Sphere drying condensate, stream 25	Spent acid scrubber, stream 34	Sintering condensate, stream 40	Spent caustic scrubber, stream 209	Debonding furnace, stream 33	Sintering furnace, stream 41	Coating furnace, stream 208	Waste and scrap handling, stream 72 ^a	Spent C ₂ Cl ₄ scrubber solution, stream 207
Heavy metals											
U (g/week) (Ci/week)	6.5(-2) ^b 3(-7)	6.5(-2) 3(-7)		5.575 2.57(-5)		0.556 2.56(-6)	0.6194 2.85(-6)	6.188 2.85(-5)	6.18(-2) 2.85(-7)	1.304 6(-6)	5.56 2.56(-5)
Pu (g/week) (Ci/week)	3.5(-2) 0.475	3.5(-2) 0.475		2.974 40.21		0.297 4.014	0.3304 4.468	3.301 44.64	3.3(-2) 0.446	0.696 9.41	2.97 40.14
^{242,244} Cm (g/week) (Ci/week)		2(-11) 1.1(-5)		1.71(-9) 9.4(-4)		1.71(-10) 9.39(-5)	1.9(-10) 1.045(-4)	1.9(-9) 1.044(-3)	1.9(-11) 1.04(-5)	4(-10) 2.2(-4)	1.71(-9) 9.39(-4)
Fission products and others											
⁹⁵ Zr (g/week) (Ci/week)		3(-7) 5.7(-3)		2.31(-5) 0.4874		2.3(-6) 4.86(-2)	2.565(-6) 5.41(-2)	2.562(-5) 0.541	2.56(-7) 5.4(-3)	5.4(-6) 0.114	2.3(-5) 0.486
⁹⁵ Nb (g/week) (Ci/week)		1(-7) 3.9(-3)		8.55(-6) 0.3352		8.53(-7) 3.34(-2)	9.5(-7) 3.724(-2)	9.49(-6) 0.372	9.48(-8) 3.72(-3)	2(-6) 7.84(-2)	8.53(-6) 0.334
^{103,106} Ru (g/week) (Ci/week)	3(-5) 0.1	3(-6) 0.01	3(-5) 0.1	2.33(-4) 0.352	2.32(-3) 8.508	2.3(-5) 8.41(-2)	2.584(-5) 9.462(-2)	5.162(-4) 1.891	2.55(-6) 9.35(-3)	5.44(-5) 0.1992	2.3(-4) 0.841
¹³⁴ Cs (g/week) (Ci/week)		2.4(-2) 30.4		4.28(-7) 5.13(-4)	4.28(-6) 5.12(-3)	4.23(-8) 5.07(-5)	4.75(-8) 5.7(-5)	9.5(-7) 1.138(-3)	4.7(-9) 5.63(-6)	1(-7) 1.2(-4)	4.23(-7) 5.07(-4)
¹³⁷ Cs (g/week) (Ci/week)		0.166 14.7		2.57(-6) 2.57(-4)	2.57(-5) 2.57(-3)	2.54(-7) 2.54(-5)	2.85(-7) 2.85(-5)	5.7(-6) 5.7(-4)	2.82(-8) 2.82(-6)	6(-7) 6(-5)	2.54(-6) 2.54(-4)
¹⁴⁴ Ce (g/week) (Ci/week)		2(-7) 5(-4)		1.37(-5) 4.28(-2)	1.37(-4) 4.27(-1)	1.35(-6) 4.22(-3)	1.52(-6) 4.75(-3)	3.04(-5) 9.49(-2)	1.5(-7) 4.69(-4)	3.2(-6) 1(-2)	1.35(-5) 4.22(-2)
¹⁵⁴ Eu (g/week) (Ci/week)		3(-8) 8(-6)		2.65(-6) 6.34(-4)	2.65(-5) 6.83(-3)	2.62(-7) 6.76(-5)	2.945(-7) 7.6(-5)	5.884(-6) 1.518(-3)	2.91(-8) 7.51(-6)	6.2(-7) 1.6(-4)	2.62(-6) 6.76(-4)
⁶⁰ Co (g/week) (Ci/week)		1(-5) 0.01		8.55(-4) 0.9756		8.53(-5) 9.74(-2)	9.5(-5) 0.1084	9.49(-4) 1.083	9.48(-6) 1.08(-2)	2(-4) 0.2282	8.53(-4) 0.974

^a It is assumed that an amount equal to 20% of stream 72 enters the cell ventilation system.

^b 6.5(-2) means 6.5 X 10⁻², etc.

Table C-4. Flow rates and chemical compositions (major radionuclides) of scrap streams in HTGR green fuel rod fabrication process

Fuel type uranium-plutonium, 10 kg HM per week, 160-day-cooled.

Stream numbers 1-74 identified in Fig. A-1, numbers 50, 72, and 202-222 in Fig. C-1

Constituent	Scrap dry microspheres, stream 30	Adherent fuel particles, stream 210	Agglomerated fuel particles, stream 211	Samples, stream 212	Particles that fail inspection, stream 213
Heavy metals					
U (g/week)	326	24.73	24.73	6.182	494.6
(Ci/week)	1.5(-3) ^a	1.14(-4)	1.14(-4)	2.85(-5)	2.28(-3)
Pu (g/week)	1.74	13.19	13.19	3.3	263.8
(Ci/week)	2.35(3)	178.4	178.4	44.6	3.568(3)
^{242,244} Cm (g/week)	1(-7)	7.59(-9)	7.59(-9)	1.9(-9)	1.52(-7)
(Ci/week)	5.5(-2)	4.17(-3)	4.17(-3)	1.04(-3)	8.3(-2)
Fission products and others					
⁹⁵ Zr (g/week)	1.35(-3)	1.02(-4)	1.02(-4)	2.56(-5)	2.05(-3)
(Ci/week)	28.5	2.162	2.162	0.541	43.24
⁹⁵ Nb (g/week)	5(-4)	3.79(-5)	3.79(-5)	9.48(-6)	7.6(-4)
(Ci/week)	19.6	1.486	1.486	0.372	29.73
^{103,106} Ru (g/week)	1.36(-2)	1.02(-3)	1.02(-3)	2.55(-4)	2.04(-2)
(Ci/week)	49.8	3.74	3.74	0.935	74.8
¹³⁴ Cs (g/week)	2.5(-5)	1.88(-6)	1.88(-6)	4.7(-7)	3.76(-5)
(Ci/week)	3(-2)	2.25(-3)	2.25(-3)	5.63(-4)	4.5(-2)
¹³⁷ Cs (g/week)	1.5(-4)	1.13(-5)	1.13(-5)	2.82(-6)	2.3(-4)
(Ci/week)	1.5(-2)	1.13(-3)	1.13(-3)	2.82(-4)	2.3(-2)
¹⁴⁴ Ce (g/week)	8(-4)	6(-5)	6(-5)	1.5(-5)	1.2(-3)
(Ci/week)	2.5	0.188	0.188	4.69(-2)	3.754
¹⁵⁴ Eu (g/week)	1.55(-4)	1.16(-5)	1.16(-5)	2.91(-6)	2.33(-4)
(Ci/week)	4(-2)	3(-3)	3(-3)	7.51(-4)	6.01(-2)
⁶⁰ Co (g/week)	5(-2)	3.8(-3)	3.8(-3)	9.48(-4)	7.58(-2)
(Ci/week)	57	4.33	4.33	1.082	86.56

^a 1.5(-3) means 1.5×10^{-3} , etc.

Measured quantities of fissile particles are separated by a riffler from the coated particle batch to approximate fuel rod channels (about 1 g of fissile particles) and then experimentally adjusted to the desired charge weight. One charge of fissile particles is mixed with premeasured quantities of fertile particles and graphite shim particles. The blended particles are poured into a mold, followed by a cylinder of pitch binder. The mold is heated to soften the binder, which is intruded by pressure through the particles. The mold is then cooled and the fuel rod ejected. A small quantity (less than 1 g) of matrix material remains on the mold and punches, which must be removed and sent (stream 218) to waste and scrap handling.

C-3 COATING FURNACE OFF-GAS

The coating furnace off-gas handling system is equipped with a perchloroethylene scrubber system (containing 114 liters of perchloroethylene) to remove particulate matter and soot entrained in the off-gas stream from the furnace. It is assumed, in applying the four coatings, that 0.1% of the batch is carried over as particulates into the off-gas (stream 205)

Table C-5. Flow rates and radionuclear compositions (major radionuclides) of main product streams in HTGR green fuel rod fabrication process
 Fuel type ^{233}U -thorium, 10 kg HM per week, 15-year-cooled.
 Stream numbers 1-74 identified in Fig. A-1, numbers 50, 72, and 202-222 in Fig. C-1

Constituent	Feed to HFEL, stream 1 (also 3, 7, 10, 12, 19, 23)	Acceptable dry microspheres stream 26	Debonded microspheres, stream 37	Sintered product, stream 43 (also 46, 50)	Coated fuel particles, stream 202	Coated fuel particles, stream 203	Coated fuel particles, stream 204
Heavy metals							
Total U (g/week) (Ci/week)	2710 36.9	2575 35.1	2572 35.06	2569 35.03	2558 34.89	2548 34.75	2289 31.19
^{232}U (g/week) (Ci/week)	0.568 12.2	0.54 11.6	0.5395 11.59	0.539 11.58	0.537 11.53	0.535 11.49	0.481 10.34
^{233}U (g/week) (Ci/week)	2483 23.5	2359 22.3	2357 22.28	2355 22.26	2345 22.17	2336 22.07	2098 19.87
^{239}Pu (g/week) (Ci/week)	4.9(-2) ^a 3(-3)	4.7(-2) 2.85(-3)	4.7(-2) 2.85(-3)	4.7(-2) 2.85(-3)	4.68(-2) 2.84(-3)	4.66(-2) 2.83(-3)	4.2(-2) 2.54(-3)
Total Th (g/week) (Ci/week)	7290 2.4(-3)	6926 2.28(-3)	6919 2.28(-3)	6912 2.28(-3)	6884 2.27(-3)	6856 2.26(-3)	6159 2.03(-3)
^{228}Th (g/week) (Ci/week)	5(-7) 4(-4)	4.75(-7) 3.8(-4)	4.745(-7) 3.0(-4)	4.74(-7) 3.0(-4)	4.72(-7) 3.78(-4)	4.7(-7) 3.77(-4)	4.22(-7) 3.38(-4)
^{232}Th (g/week) (Ci/week)	7290 2(-3)	6926 1.9(-3)	6919 1.9(-3)	6912 1.9(-3)	6884 1.89(-3)	6856 1.88(-3)	6159 1.69(-3)
Other							
^{60}Co (g/week) (Ci/week)	1.1 ^b 1211 ^b	1.045 1151	1.044 1150	1.043 1149	1.039 1144	1.035 1140	0.929 1024

^a4.9(-2) means 4.9×10^{-2} , etc.

^bAdded between streams 7 and 10.

and that 90% of the particulates are removed by the perchloroethylene scrubber. The perchloroethylene scrubbing medium is replaced with fresh perchloroethylene after 30 runs, the spent solution being sent to waste and scrap handling as organic waste (stream 207). The spent perchloroethylene will be absorbed on vermiculite, encased in plastic, and disposed of by land burial. A caustic spray scrubber (1.5 M NaOH) is provided downstream of the perchloroethylene scrubber to neutralize and remove hydrogen chloride gas (removal efficiency 99.9%) produced by the decomposition of methyltrichlorosilane during silicon carbide coating. An additional 9% of the particulates from the coating furnace off-gas stream are removed by the caustic scrubber. The caustic scrubber is provided with an impingement separator and cooler to prevent caustic from escaping into the off-gas system downstream. The caustic solution is periodically replaced, the spent solution being sent to hot liquid waste (stream 209). The off-gases from the caustic scrubber, containing hydrogen, various hydrocarbon gases, and the remaining 1% of the particulates from the coating furnace, are routed to combustible off-gas (stream 208).

Table C-6. Flow rates and radionuclear compositions (major radionuclides) of liquid wastes, combustible off-gas, hot off-gas, and organic wastes in the HTGR green fuel rod fabrication process

Fuel type ^{233}U -thorium, 10 kg HM per week, 15-year-cooled. Stream numbers 1-74 identified in Fig. A-1, numbers 50, 72, and 202-222 in Table C-1

Constituent	Liquid wastes				Combustible off-gas			Hot off-gas		Organic wastes,
	Evaporator condensate, stream 6	Gel-sphere wash, stream 22	Spent acid scrubber, stream 34	Spent caustic scrubber, stream 209	Debonding furnace, stream 33	Sintering furnace, stream 41	Coating furnace, stream 208	Waste and scrap handling, stream 72	Microsphere preparation, streams 4, 8, 13, 24	Spent C_2Cl_4 scrubber solution, stream 207
Heavy metals										
Total U (g/week)	2.7(-2) ^a	2.7(-2)	2.32	0.231	0.257	2.572	2.57(-2)	0.542		2.312
(Ci/week)	3.7(-4)	3.7(-4)	3.2(-2)	3.16(-3)	3.51(-3)	3.5(-2)	3.5(-4)	7.38(-3)		3.15(-2)
^{232}U (g/week)	6(-6)	6(-6)	4.86(-4)	4.86(-5)	5.4(-5)	5.4(-4)	5.4(-6)	1.14(-4)		4.86(-4)
(Ci/week)	1.2(-4)	1.2(-4)	1.04(-2)	1.04(-3)	1.16(-3)	1.16(-2)	1.16(-4)	2.44(-3)		1.04(-2)
^{233}U (g/week)	2.5(-2)	2.5(-2)	2.123	0.212	0.236	2.357	2.36(-2)	0.497		2.12
(Ci/week)	2.4(-4)	2.4(-4)	2.01(-2)	2.01(-3)	2.23(-3)	2.23(-2)	2.23(-4)	4.7(-3)		2.01(-2)
^{239}Pu (g/week)	5(-7)	5(-7)	4.2(-5)	4.23(-6)	4.7(-6)	4.7(-5)	4.71(-7)	9.8(-6)		4.23(-5)
(Ci/week)	3(-8)	3(-8)	2.57(-6)	2.57(-7)	2.85(-7)	2.85(-6)	2.85(-8)	6(-7)		2.57(-6)
Total Th (g/week)	7.3(-2)	7.3(-2)	6.233	0.622	0.693	6.919	6.3(-2)	4.49		6.22
(Ci/week)	2(-8)	2(-8)	2.05(-6)	2.05(-7)	2.28(-7)	2.28(-6)	2.28(-8)	1.17(-6)		2.05(-6)
^{228}Th (g/week)	5(-12)	5(-12)	4.28(-10)	4.27(-11)	4.75(-11)	4.745(-10)	4.74(-12)	1(-10)		4.27(-10)
(Ci/week)	4(-9)	4(-9)	3.42(-7)	3.42(-8)	3.8(-8)	3.8(-7)	3.8(-9)	8(-8)		3.42(-7)
^{232}Th (g/week)	7.3(-2)	7.3(-2)	5.233	0.622	0.693	6.919	6.91(-2)	4.49		6.22
(Ci/week)	2(-8)	2(-8)	1.71(-6)	1.71(-7)	1.9(-7)	1.9(-6)	1.9(-8)	7.28(-7)		1.71(-6)
Other										
^{60}Co (g/week)		1(-5)	3.41(-4)	9.41(-5)	1.045(-4)	1.044(-3)	1.04(-5)	2.2(-4)		9.4(-4)
(Ci/week)		0.01	1.035	0.103	0.1151	1.15	1.15(-2)	0.242		1.034
^{219}Rn (g/week)					1.14(-19)	8.43(-19)			2.66(-19)	
(Ci/week)					1.4(-9)	1.09(-8)			3.42(-9)	
^{220}Rn (g/week)					2.27(-9)	1.64(-8)			5.14(-9)	
(Ci/week)					2.08	14.39			4.71	
^{222}Rn (g/week)					4.81(-14)	4.63(-14)			5.23(-15)	
(Ci/week)					7.42(-9)	7.26(-9)			8.06(-10)	

^a2.7(-2) means 2.7×10^{-2} , etc.

Table C-7. Flow rates and radionuclear compositions (major radionuclides) of scrap streams in HTGR green fuel rod fabrication process

Fuel type ^{233}U -thorium, 25% fissile content, 10 kg HM per week, 15-year-cooled.
Stream numbers 1-74 identified in Fig. A-1, numbers 50, 72, and 202-222 in Fig. C-1

Constituent	Scrap dry microspheres, stream 30	Adherent fuel particles, stream 210	Agglomerated fuel particles, stream 211	Samples, stream 212	Particles that fail inspection, stream 213
Heavy metals					
Total U (g/week)	135.5	10.28	10.28	2.569	205
(Ci/week)	1.845	0.14	0.14	0.035	2.8
^{232}U (g/week)	2.84(-2) ^a	2.16(-3)	2.16(-3)	5.4(-4)	4.32(-2)
(Ci/week)	0.61	4.64(-2)	4.64(-2)	1.16(-2)	0.928
^{233}U (g/week)	124.2	9.42	9.42	2.355	188.5
(Ci/week)	1.175	8.92(-2)	8.92(-2)	2.23(-2)	1.784
^{239}Pu (g/week)	2.45(-3)	1.88(-4)	1.88(-4)	4.7(-5)	3.76(-3)
(Ci/week)	1.5(-4)	1.14(-5)	1.14(-5)	2.85(-6)	2.28(-4)
Total Th (g/week)	364.5	27.65	27.65	6.912	553
(Ci/week)	1.2(-4)	9.12(-6)	9.12(-6)	2.28(-6)	1.82(-4)
^{228}Th (g/week)	2.5(-8)	1.9(-9)	1.9(-9)	4.74(-10)	3.79(-8)
(Ci/week)	2(-5)	1.52(-6)	1.52(-6)	3.8(-7)	3.04(-5)
^{232}Th (g/week)	364.5	27.65	27.65	6.912	553
(Ci/week)	1(-4)	7.6(-6)	7.6(-6)	1.9(-6)	1.52(-4)
Other					
^{60}Co (g/week)	5.5(-2)	4.17(-3)	4.17(-3)	1.043(-3)	8.34(-2)
(Ci/week)	60.55	4.596	4.596	1.149	91.8

^a2.84(-2) means 2.84×10^{-2} , etc.

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